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# BULLETIN

OF THE

## AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

## 1961 THANKSGIVING MEETING

AT THE

UNIVERSITY OF CHICAGO, CHICAGO, ILLINOIS

November 24–25, 1961

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# BULLETIN

of the

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## Concerning "Abstracts"

Many people have the not unreasonable idea that the "abstracts" in this Bulletin are abstracts of written texts of which we have the originals. This is not the case. These are the abstracts of speeches which are to be given at the meeting in question. We have no texts, and those who wish more information than an abstract contains must appeal to its author. Every member of the Society has the right to give ten-minute papers before its meetings.

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November 24, 1961 Series II, Vol. 6, No. 5

# BULLETIN

OF THE

# AMERICAN PHYSICAL SOCIETY

1961 Thanksgiving Meeting at the University of Chicago, November 24–25, 1961

THE Thanksgiving Meeting once more returns to the University of Chicago. The University of Chicago has often played host to the Thanksgiving Meeting. It is fortunate that there are three separate divisions of the University of Chicago which can act as our hosts: The Department of Physics, The Institute for the Study of Metals, and the Enrico Fermi Institute for Nuclear Studies. This time our host is the Institute for the Study of Metals, whose Acting Director is M. G. Inghram. Mr. Don McGiffin, the Administrative Assistant of the Institute, has made the arrangements for the meeting.

The dates of our convention are Friday and Saturday, November 24 and 25.

**The Hotel Windermere,** 1642 East 56th Street, Chicago 37, Illinois, again has accepted the responsibility of housing those of our members who apply up to the moment when it is booked fully and of finding accommodations in other hotels in the region for those who write later. In writing to the Windermere, mention that you are coming to the meeting of The American Physical Society.

Although Chicago is the usual theater of our Thanksgiving meetings, some people may be unfamiliar with the Chicago area. Even those familiar with the area should read the following paragraphs, since the travel arrangements have changed. The University is about seven miles south of the "Loop" or downtown business district of Chicago. There are no hotels within a half-mile of the University; the nearest group of hotels, of which the Windermere is one, lies three-quarters of a mile or thereabouts to the east and northeast. The only good way to go from the Loop to the University is to take a suburban train of the Illinois Central Railroad from Michigan Avenue at Randolph Street, or at Van Buren Street, and get off at the station marked "55th-56th-57th Street," which is adjacent to the Windermere. There is a taxi stand at the east side of the 56th Street exit. There is a bus stop west of the station at 55th Street and Lake Park. The bus marked "55-Morgan" can be taken west along 55th Street to University Avenue. Walking south on University to 58th Street will bring one to Eckhart Hall where the registration and the social center will be. It is a little more than a half-mile walk from the 55th-56th Street station to Eckhart Hall. The best route to take is to walk west on 56th Street and then turn left on University Avenue. The bus marked "55-Morgan" can be taken from the Windermere Hotel to Eckhart Hall. It stops at the southeast corner of 56th Street and Hyde Park Boulevard across the street from the Windermere Hotel.

Arriving in Chicago by the New York Central or Pennsylvania Railroad, it might be possible to detrain at the Englewood Station (63rd Street). However, many passenger trains no longer stop there, proceeding directly downtown, so it would be wise to check on this point. Coming by the Illinois Central Railroad, one can leave the train at the Woodlawn Station (63rd Street). We understand that the only New York Central trains that still stop at the Woodlawn Station are those from Cincinnati.

Those arriving in Chicago by air should take note of the fact that there are two airports in Chicago: Midway and O'Hare. The quickest way to get from Midway airport to the University of Chicago is to take a taxi. The cost should be about $3.00. If you go by airport coach you will pay $1.45 to get to the Loop and then will have the problem of getting from the Loop to the University. If you come in at O'Hare field, where all of the jets arrive, the quickest and most interesting way to get from the airport to the University is to take the helicopter service from O'Hare to Meigs field near the Loop at a cost of $6.00, and then take a taxi which should cost about $2.50. The regular airport bus from O'Hare field to the Loop takes a little over one hour and costs $2.25. A map of the University of Chicago area appears on page 496 of this Bulletin.

The **registration desk** will be situated on the second floor of Eckhart Hall. Members and guests alike must register and pay the modest registration fee of one dollar. **Banquet tickets** will be sold at the registration desk. Announcements of **post-deadline papers,** if any, will be made on blackboards adjacent to the desk. Notice of messages for members may be handed in only by people who have paid the registration fee, and such notices also will appear on these blackboards.

Invited papers will be given by A. C. Anderson, J. D. Anderson, F. J. Blatt, F. Bloch, R. Coté, L. Foldy, S. C. Fultz, H. Fritzsche, W. M. Fairbank, P. Franken, A. V. Gold, R. Herb, D. Inglis, E. Lynn, B. Maglic, C. Phillips, D. Ravenhall, F. Rohrlich, D. K. Robinson, A. J. F. Siegert, K. Symon, and W. A. Wallenmeyer.

No symposia have been arranged for this meeting, but some of the groups of papers display such a unity of topic that they have been called by that name, e.g., Session G on Superconductors, Session R on Low Energy Nuclear Physics, etc.

The Deputy Secretary wishes to express his gratitude to Dr. M. Hamermesh, Director of the Physics Division of the Argonne National Laboratory, for his advice and help in arranging for the invited papers for this meeting and to Dr. Peter Pryce of IBM for his assistance in arranging the solid-state sessions.

Two hundred and eight contributed papers are distributed among 22 sessions, more than at any previous Thanksgiving meeting. It is gratifying to see the Thanksgiving meeting finally reflecting the general growth of the Society after remaining remarkably constant in size for the past five years. Many members of the Society have suggested that the autumn meeting be held much earlier than Thanksgiving. In that case, however, the deadline would have to be in the middle of the summer, which the Secretary and the Deputy Secretary believe to be impractical. The difficulties the Deputy Secretary encountered in arranging this meeting, because of people being out of the country or on vacation even as late as the third week in September, strengthens his opinion that a midsummer deadline would be undesirable.

The **banquet of the Society** will be held on Friday, November 24, at 7:00 p.m. in the Quadrangle Club, 1155 East 57th Street, at the corner of University Avenue. The after-dinner speaker will be Chancellor George Beadle of the University of Chicago. Tickets at $4.50 will be on sale at the registration desk, and a form for advance reservations is printed on page 495 of this Bulletin. You are very specially asked to make use of this form, for at this meeting we face the "guarantee hazard" to an aggravated degree. This banquet always presents us with a special problem owing to the ineluctable fact that it must be held on the first day of the meeting. The Society must make a guarantee to the Quadrangle Club even before the meeting begins. Hotels can often adapt themselves to the number of ticket buyers even a few hours before the dinner, but the situation of a club is different, and the Quadrangle Club requires a guaranteed estimate several days before the meeting begins. If we set the guarantee too low, some people will be frustrated by finding that there are no tickets left when they come to buy, but if we set it too high the Society loses money. We are willing to risk some loss for the sake of this, the one unifying feature of the meeting, the only one which all members can attend because there are no simultaneous session to divide them. However, we are afraid to risk too much. We implore the members to fill out and mail the form to be found on the lower half of page 495. Those who pay by check mailed with the form, and received not later than November 21, will find their tickets waiting for them at the desk. Those who do not fill out the form are asked to buy tickets as early as possible on Friday. Cocktails may be purchased in the library of the Quadrangle Club from 6 p.m. on.

The **Council of The American Physical Society** will meet at 9:30 a.m. on Friday in Room 180 of the Research Institute building, 5640 South Ellis Avenue.

**Post-deadline ten-minute papers,** pertaining to very recent achievements of very special importance will be considered for admission to the special supplementary program if the abstracts are received at the office of the Society not later than Friday, November 17. The titles of such papers as are accepted will be written on a blackboard near the registration desk, and opportunity for presentation of the papers will be given at the end of Session V or possibly elsewhere in the program.

Prospective meetings and deadlines of the Society will be found listed on page 493 of this Bulletin. Preliminary announcements of the 1962 Annual Meeting at New York and of the 1962 Southwestern Meeting at Austin, Texas will be found on page 488.

**Make a habit of reading the instructions for the preparation of abstracts,** which appear in all issues of the Bulletin and which in this one are to be found on page 494. From time to time they become more stringent, for their purpose is to reduce the waste of labor and loss of time spent in editing (i.e., getting ready for the press) abstracts that are badly

prepared. Indeed, some of the advice that has been repeatedly given for years is not universally heeded; we are still getting occasional abstracts that are single spaced, offered only as carbon copies, paragraphed, or longer than is allowed. We are on the verge of rejecting all abstracts that do not conform to instructions because of the recent explosion of the number of abstracts submitted for meetings.

**Errata** pertaining to abstracts in this Bulletin will be published in a later issue of this Bulletin if received not later than Monday, November 27, by Miss Ruth F. Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Write out the corrections in the form (instead of . . . read . . .). Do not add anything. The privilege of inserting errata is not accorded to enable people to publish additional data or to restore material cut out because the abstract was too long.

W. W. HAVENS, JR., *Deputy Secretary*
American Physical Society
Columbia University
New York 27, New York

# EPITOME OF THE 1961 CHICAGO MEETING

Personal names of those of invited speakers, except at the end of lines where they are those of halls.

## Friday Morning

A. Franken; optical masers and photo effects. Mandel Hall.
B. Nuclear reactions I. Breasted Hall.
C. Slow neutrons and fission. Eckhart 133.
D. Defects and radiation damage. Judd 126.
E. Electron emission from surfaces. Social Sciences 122.
F. General physics. Rosenwald 2.

## Friday Afternoon

G. Fairbank, Bloch, Symon; Superconductors. Mandel Hall.
H. Fritzsche; semiconductors I. Breasted Hall.
I. Nuclear moments and beta-gamma spectroscopy I. Judd 126.
J. Fast neutrons and other nuclear physics. Eckhart 133.
K. Theoretical physics. Social Sciences 122.
KA. High-energy physics. Rosenwald 2.

## Friday Evening at 7:00

Banquet of the American Physical Society. Quadrangle Club.

## Saturday Morning

L. Robinson, Maglić, Coté, Lynn. Mandel Hall.
M. Semiconductors II. Breasted Hall.
N. Foldy, Rohrlich, Siegert, Ravenhall. Judd 126.
O. Blatt, Gold; Metals and semi metals. Eckhart 133.
P. Nuclear reactions II. Social Sciences 122.
Q. Apparatus of nuclear physics and Mössbauer effect. Rosenwald 2.

## Saturday Afternoon

R. Inglis, Herb, Fultz, Anderson. Mandel Hall.
S. Nuclear and electron spin resonance. Breasted Hall.
T. Wallenmeyer; The MURA accelerator. Judd 126.
U. Anderson, Phillips. Solid-state theory. Social Sciences 122.
V. Solid state, general. Rosenwald 2.
W. Beta and gamma spectroscopy II. Eckhart 133.

# PROGRAMME

FRIDAY MORNING AT 10:00 a.m.

Mandel Hall

(L. S. GOODMAN, presiding)

## *Optical Masers and Photo Effects*

### *Invited Paper*

**A1. Generation of Optical Harmonics.** P. FRANKEN, *University of Michigan.* (30 min.)

### *Contributed Papers*

**A2. Giant Optical Pulsations from Ruby.*** F. J. MCCLUNG AND R. W. HELLWARTH, *Hughes Research Laboratories.*—Giant pulses of optical maser radiation have been produced which are several orders of magnitude larger than the commonly observed spontaneous pulses. The pulses were produced by varying the effective reflectivity of the reflecting surfaces at the ends of the ruby rod through a Kerr-cell switching technique. The measured pulse characteristics are found to be in agreement with theoretical predictions.

* This work supported in part by the U. S. Air Force.

**A3. Theoretical Considerations of Optical Maser Radiation.* 1. The Resonant Mode Structure of a Ruby Fabry-Perot Cavity.** M. RESNIKOFF AND YOH-HAN PAO, *University of Chicago.*—In connection with the formulation of a quantum theory for optical maser action, the electromagnetic resonant mode structures of ruby rods have been examined theoretically. Of interest is the fact that total internal reflection at a bounded surface is accompanied by a loss of energy from the internal modes. Analytical expressions for the modes, the rate of energy loss for each mode, and the density of modes as a function of frequency and propagation vector are given in this paper.

* Supported by the U. S. Air Force Systems Command.

**A4. Theoretical Considerations of Optical Maser Radiation.* 2. A Quantum Mechanical Description of Stimulated Emission within a Multimode Cavity.** YOH-HAN PAO AND M. RESNIKOFF, *University of Chicago.*—The essential difference between theoretical descriptions of maser action at microwave and optical frequencies is that the latter contains additional nonlinear features due to coupling of modes in multimode cavities. Quantum mechanical equations describing the interaction between the atomic and radiation systems within such a multimode cavity have been formulated and numerical solutions have been obtained for cases of interest. It is found that in pulsed operation a considerable amount of frequency modulation of the mode frequencies can be obtained. Furthermore, it is found that oscillations in the intensity of the transmitted radiation need not be due to the competing effects of the rates of optical pumping and the rate of depletion of excited states by stimulated emission. Such low-frequency oscillations can also be obtained as the result of the mixing of modes of very nearly the same frequency by photodetectors.

* Supported by the U. S. Air Force Systems Command.

**A5. Feedback Modulation with a Ruby Optical Maser.** R. J. COLLINS AND P. KISLIUK, *Bell Telephone Laboratories, Inc.*—During the oscillation period in an optical maser the induced emission decreases the lifetime of the upper level thereby limiting the possible population inversion for a given pumping power. This limitation of the inversion level in turn limits the output peak power. Through modulation of the optical feedback an increase in the output peak power is therefore possible.[1] To observe this effect a pulsed ruby optical maser was constructed with detached mirrors allowing a shutter to be placed between ruby and one mirror. In this way a variable delay could be introduced between the application of the pumping source and application of the optical feedback. The rate of restoration of feedback can be: (1) fast compared to the buildup time of maser oscillation, (2) comparable to the duration of a single "spike," or (3) slow compared to duration of a spike. Results for case (2) where the peak powers were increased by a factor of ~10 will be discussed. A study of the spiking behavior of a ruby maser in the absence of pumping radiation was made by delaying the application of feedback until after the pumping source had been extinguished.

[1] R. W. Hellwarth, Second International Conference on Quantum Electronics.

**A6. Stimulated Emission into Optical Whispering Modes of Spheres.** C. G. B. GARRETT, W. KAISER, AND W. L. BOND, *Bell Telephone Laboratories, Inc.*—Spherical samples of $CaF_2:Sm^{2+}$, maintained at 20°K, have been exposed to high-intensity pulsed illumination. When the intensity exceeds a certain well-defined threshold, the character of the emission of fluorescent light from the surface of the sphere becomes changed. As the intensity is raised beyond the threshold, an increasing fraction of the light is emitted nearly tangentially from each point on the surface. The light emitted in this way is found to be polarized with the $E$ vector radial. The observations are interpreted as indicating stimulated emission oscillations in "whispering modes" of the sphere, which have been analyzed in terms of the electromagnetic analog of the Rayleigh theory of the whispering gallery.

**A7. Fluorescence and Stimulated Emission of $Nd^{3+}$ in $CaWO_4$.** L. F. JOHNSON AND K. NASSAU, *Bell Telephone Laboratories, Inc.*—Strong infrared fluorescence of trivalent neodymium ions in calcium tungstate has been observed consisting of three groups centered about 7300, 9400, 11 200 $cm^{-1}$ (1.37, 1.06, and 0.9 $\mu$). The groups are $4f^3$ transitions and correspond, respectively, to $^4F_{3/2} \rightarrow {}^4I_{13/2}$, $^4F_{3/2} \rightarrow {}^4I_{11/2}$, and $^4F_{3/2} \rightarrow {}^4I_{9/2}$ transitions of the free ion (ground state $^4I_{9/2}$). The terminal state of the most intense group, $^4I_{11/2}$, lies some 2000 $cm^{-1}$ above the ground state. The strongest line within this group, at 1.06 $\mu$, has a half-width of about 7 $cm^{-1}$ at 77°K. This line has been found to exhibit stimulated emission at room temperature and 77°K characterized by a threshold ~5 joules at room temperature and well-defined relaxation oscillations superimposed on a continuum of stimulated emission. Details of the nature of the stimulated emission will be described.

**A8. Electron-Spin-Resonance and Photoconductivity Studies of the Cubic-Tetragonal Phase Transition in $BaTiO_3$.*** J. L. BJORKSTAM, W. R. ELLIOTT, T. R. BILLETER, AND A. J. GIAROLA, *University of Washington.*—An abrupt change in the ESR spectrum of $Fe^{3+}$ impurities at the Curie temperature has been previously reported.[1] In addition we find an abrupt change in the decay time of photo-injected carriers at this transition. We have used both these effects in a study of the nature of the phase transition with different concentrations and types of impurities. Investigations include the effects of applied electric field as well as a search for dependence of transition temperature on photoconductivity.

* Supported in part by the National Science Foundation.
[1] A. W. Hornig, R. C. Rempel, and H. E. Weaver, J. Phys. Chem. Solids 10, 1 (1959).

**A9. Photo-Equilibrium between *F* and *F'* Centers in KCl at 80°K.*** A. COSTIKAS AND L. I. GROSSWEINER, *Illinois Institute of Technology.*—The photo-equilibrium between *F* and *F'* centers, established by "*F* light" incident on the KCl *F* band,[1] has been studied by monitoring the *F* band with weak monochromatic light while cross-illuminating the crystal with high-intensity "saturation" light. Cross-illumination with "*F* light" induces a transmission increase, and cross-illumination with "*F'* light" (600–1100 mμ) induces a transmission decrease, the latter saturating at very low light intensities. All transmission changes are completely reversible, with build-up and decay time constants varying linearly with light intensity from 0.1–10 sec. The fraction of *F* centers transformed into *F'* centers is independent of the *F*-center concentration but depends on the intensity of the "*F* light." These transformations are substantially the same for additively colored crystals and for crystals x-rayed at 80° or 300°K. The initial quantum efficiency for bleaching *F* centers is $0.06 \pm 0.02$. By fitting the experimental data to a simple model, the electron capture cross section of an *F* center can be shown to be smaller than the electron capture cross section of a negative ion vacancy by a factor of $10^{-3}$.

* Supported by the U. S. Atomic Energy Commission.
[1] A. R. Reinberg and L. I. Grossweiner, Phys. Rev. 122, 1734 (1961).

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## FRIDAY MORNING AT 9:30 a.m.

## Breasted Hall, The Oriental Institute

(J. P. SCHIFFER presiding)

### *Nuclear Reactions I*

**B1. Excitation Function and Angular Distributions for the $Li^7(p,\alpha)\alpha$ Reaction.*** I. G. HAN AND N. P. HEYDENBURG,† *Florida State University.*—The excitation function for the $Li^7(p,\alpha)\alpha$ reaction has been studied for proton bombarding energies from 2.75–12.0 Mev. In addition to the 3-Mev resonance peak observed in previous work,[1] a prominent peak was observed at 5.6 Mev with an asymmetry at the higher energy side indicating an unresolved resonance at about 6.5 Mev. Twenty angular distributions have been obtained over this energy range. The angular distributions near the 5.6-Mev peak show similar patterns to those near the 3-Mev resonance having a maximum at 90° (c.m.). The resonance at 5.6 Mev is probably due to a $J=2^+$ level in $Be^8$. The angular distributions from 6.5–7.5 Mev also indicate a rather broad resonance at about 6.5 Mev. The angular distributions from 9.5–12.0 Mev are similar and the yield remains almost constant. Similar work on $Li^6$ is in progress.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† Also DTM, Carnegie Institution of Washington.
[1] N. P. Heydenburg, C. M. Hudson, D. R. Inglis, and W. D. Whitehead, Jr., Phys. Rev. 73, 241 (1948); *ibid.* 74, 405 (1948).

**B2. $Li^7(He^3,p)Be^9$, $Li^7(He^3,\alpha)Li^6$, and $Li^7(He^3,t)Be^7$ Reactions.** E. A. WOLICKI AND A. R. KNUDSON, *U. S. Naval Research Laboratory.*—A 20-in., 180° double-focusing magnetic spectrometer has been used to analyze charged particles produced by bombarding $Li^7$ with $He^3$. For the $Li^7(He^3,p)Be^9$ reaction differential cross sections were measured for the ground state proton group at 3.20 and 4.50 Mev. At3.20 Mev, the anisotropy is small. At 4.50 Mev, the minima and maxima are more pronounced. Excitation curves obtained at laboratory angles of 20°, 50°, and 165° in the range from 2.5–4.8 Mev are relatively flat, those at 20° and 50° showing a weak maximum at approximately 3.3 Mev. For the $Li^7(He^3,\alpha)Li^6$ reaction differential cross sections were measured for the ground state alpha group at 4.5 Mev. The angular distribution is peaked at 0° and at large angles. The minimum at 113° is less than one-third as large as the forward and backward peaks. An excitation curve obtained at 20° in the range from 1.75–4.75 Mev shows a weak maximum at 2.1 Mev. Differential cross sections for the ground state group in the reaction $Li^7(He^3,t)Be^7$ were measured at 4.50 Mev. The anisotropy is small, the yield rising slightly toward large angles.

**B3. $Be^9(p,\alpha)Li^6$ and $B^{11}(p,\alpha)Be^8$ Reactions.*** H. R. BLIEDEN, G. M. TEMMER,† AND K. L. WARSH, *Florida State University.*—The reaction $Be^9(p,\alpha)Li^6$ has been studied for proton energies between 3.5 and 12 Mev with our Tandem accelerator. The charged particles were detected by solid-state counters. The total cross section for $\alpha$-particle emission is a smooth, monotonically decreasing function of energy. The shape of the angular distributions of $\alpha_0$ and $\alpha_1$ obtained between 6 and 11.5 Mev changes remarkably little. The $\alpha_0$ angular distributions show a broad maximum at $\theta$ c.m. ~60°, a minimum at $\theta$ cm ~115°, and strong backward peaks in all cases. The $\alpha_1$ angular distribution has one shallow minimum at $\theta$ cm ~65°. At the higher energies, the $\alpha_2$ angular distribution was also observed. These results will be discussed in terms of the direct and exchange modes of the triton pickup process. The excitation curve for $B^{11}(p,\alpha)Be^8$ shows pronounced structure in contrast to the former reaction. Details of this reaction will also be discussed.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† Also, DTM, Carnigie Institution of Washington.

**B4. $C^{12}(\alpha,\alpha_1)C^{12*}$ Reaction from 10 to 19 Mev.*** G. E. MITCHELL, E. B. CARTER, AND R. H. DAVIS, *Florida State University.*—The excitation curves for the reaction $C^{12}(\alpha,\alpha_1)C^{12*}$ ($Q=-4.43$ Mev) have been measured at six fixed laboratory angles for the range of bombarding energy 10 to 19 Mev. Considerable structure is observed on all of these excitation functions. Fifteen detailed angular distributions were taken. These angular distributions show qualitatively the direct inelastic diffraction pattern, especially at the higher energies. At 14 Mev and below, there are minima at approximately 60° and 120°; above 14 Mev, there are minima at about 60°, 90°, and 120°. The back angle behavior is irregular. A qualitative change

observed in the character of the angular distributions near 14 Mev was also found in the $C^{13}(\alpha,\alpha_1\gamma_{4.43})C^{13}$ reaction.[1]

* Supported in part by U. S. Air Force Office of Scientific Research.

[1] G. E. Mitchell, E. B. Carter, and R. H. Davis, Bull. Am. Phys. Soc. 6, 227 (1961).

**B5. Excitation Curves and Angular Distributions of 10- to 19-Mev Alpha Particles Elastically Scattered from Carbon.*** E. B. Carter, G. E. Mitchell, and R. H. Davis, *Florida State University.*—Excitation curves from 10- to 19-Mev bombarding energy have been taken in about 50-kev steps at thirteen angles. These curves are dominated by several broad anomalies with widths up to 1 Mev; in addition, there are about twenty narrow anomalies superimposed. The angular distribution at 11 Mev is fit fairly well with the Blair model with cutoff angular momentum equal to 5. The minima in the experimental angular distributions are not as deep as the Blair model predicts. The irregular dependence of the angular distributions on energy may be characterized by listing the energies and the observed number of minima: 11 Mev—4 or 5; 11.74 Mev—4 or 5; 12.1 Mev—6; 12.46 Mev—4; 13 Mev—4; 14 Mev—4; 14.42 Mev—4; 14.53 Mev—4 or 5; 15 Mev—5; 16 Mev—5; 17 Mev—5 or 6; 17.5 Mev—6; 18 Mev—7; 18.5 Mev—5 or 6; 19 Mev—4.

* Supported in part by the U. S. Air Force Office of Scientific Research.

**B6. $C^{13}(He^3,n)O^{15}$ Reaction.** R. F. Gabbard,* P. D. Miller,† and J. L. Duggan,‡ *Oak Ridge National Laboratory.*—Pulsed beam time-of-flight techniques, with time resolution capabilities of 4 mμsec for neutrons,[1] have been used to study neutrons from the ground state and third excited state (6.15 Mev) for the reaction $C^{13}(He^3,n)O^{15}$. Excitation functions were measured at 0°, and 90° for $He^3$ energies from 1–2.7 Mev. Angular distributions were measured at a $He^3$ energy of 2.66 Mev. The IBM 7090 distorted wave code of Satchler *et al.*[2] has been used to fit these angular distributions. Tentative fits show $l=0$ and $l=3$ for the ground state and third excited states, respectively. From these transfers, preliminary assignments of $(\frac{1}{2}^-)$ for the ground state and $(\frac{7}{2}^+ \rightarrow \frac{7}{2}^+)$ for the third excited state have been made. Distorted wave calculations will also be shown for previously reported measurements[3] on $Be^9(He^3,n)C^{11}$ and $Li^7(He^3,n)B^9$. The improvements of distorted wave fits over those from plane-wave calculations will be shown.

* Summer Research Participant from the University of Kentucky.
† On leave at AERE, Harwell.
‡ ORINS Fellow from Louisiana State University, now at the University of Georgia.

[1] W. M. Good and R. F. King, Bull. Am. Phys. Soc. 6, 457 (1961), this issue.
[2] G. R. Satchler, R. M. Drisko, and R. H. Bassel, Bull. Am. Phys. Soc. 6, 66 (1961).
[3] P. D. Miller, J. L. Duggan, and R. F. Gabbard, Bull. Am. Phys. Soc. 6, 60 (1961).

**B7. Elastic Scattering of Deuterons by $N^{14}$.*** C. H. Jones, R. F. Seiler, K. W. Jones, and D. F. Herring, *The Ohio State University.*—Absolute differential cross sections for the elastic scattering of deuterons by $N^{14}$ have been measured from 0.67 to 2.0 Mev at center of mass angles 90°, 125.3°, 140.8°, and 166.5° with deuterons from The Ohio State University electrostatic accelerator. The $N^{14}$ target gas was contained in a differentially pumped gas scattering chamber. The elastic deuterons were detected with a solid state detector. No narrow resonances were found. A single broad anomaly exhibiting destructive interference at all angles was observed.

* This work was supported in part by the U. S. Atomic Energy Commission and The Ohio State University Development Fund.

**B8. Differential Cross Sections of the $N^{14}(t,d_0)N^{15}$ Reaction.** R. B. Schwartz, L. M. Cameron, and H. D. Holmgren,* *Nucleonics Division, U. S. Naval Research Laboratory.*—The tritium beam of the Nucleonics Division 2-Mv Van de Graaff accelerator was used to bombard a thin carbon-adenine-titanium target for the investigation of the $N^{14}(t,d_0)N^{15}$ reaction. Differential cross sections as functions of angle and of bombarding energy have been measured in the bombarding energy range from about 1 to 2 Mev. The deuterons leading to the ground state of $N^{15}$ were selected from other charged particle groups by a $dE/dx$ and $E$ counter system consisting of a thin-window, gas-filled proportional counter (operated at a pressure such that the deuterons lost about 300 kev energy) followed by a 0.03-in. thick CsI crystal mounted on a type 6292 multiplier phototube. The deuteron angular distribution at a bombarding energy of 1.5 Mev shows a single broad minimum and is generally symmetric about 90°, although the minimum itself actually occurs at about 110°. At 1.975 Mev, the minimum has shifted forward to about 80° and a pronounced forward maximum has appeared. The yield, measured at 150° shows an increase with bombarding energy in the range 1 to 2 Mev.

* Present address: Physics Department, University of Maryland, College Park, Maryland.

**B9. Differential Cross Sections of the $N^{14}(t,\alpha)C^{13}$ Reactions.** L. M. Cameron, H. D. Holmgren,* and R. B. Schwartz, *U. S. Naval Research Laboratory.*—The differential cross sections between 90° and 165° for the ground-state and the first excited-state alpha particles from the reaction $N^{14}(t,\alpha)C^{13}$ were measured as functions of the bombarding energy from 1 to 2 Mev. The yield curves for the ground-state group increase rapidly with increasing bombarding energy below 1.55 Mev and appear to level off above this energy. However, the curves for the first excited-state group continue to increase rapidly up to about 1.85 Mev. This 300-kev difference may indicate a higher Coulomb barrier for the reactions emitting the alpha particle to the first excited state. The yield curves for the ground-state alpha particles at 135°, 150°, and 165° show relative minima at about 1.82 Mev. The angular distribution of the ground-state group exhibits a strong forward maximum (which increases with bombarding energy), a secondary maximum at about 90°, a backward maximum, and minima at about 60° and 140°. The angular distribution for the first excited state group shows a weak maximum in the backward direction. Angular distributions will be presented for the combination of the second and third excited states (not resolved), the sixth excited state, and the combination of the seventh and eight excited states (not resolved). The relative intensities of these groups at 1.975 Mev are $\alpha_0=1.00$, $\alpha_1=0.43$, $\alpha_{2+3}=1.96$, $\alpha_6=0.72$, $\alpha_{7+8}=5.96$.

* Present address: Physics Department, University of Maryland, College Park, Maryland.

**B10. Isotopic-Spin Selection Rule Violation in $N^{14}(d,\alpha)C^{12}$.** W. A. Schier and C. P. Browne, *University of Notre Dame,* and I. F. Wright, *University of Wisconsin.**—The $N^{14}(d,\alpha)C^{12}$ reaction was observed at 90° with incident deuteron energies ranging from 4.75–10 Mev. The deuterons were accelerated by the University of Wisconsin tandem accelerator. A gas cell was used in which a surface barrier detector, gated by a proportional counter to remove elastic deuterons, energy-analyzed the $\alpha$ spectrum. The $\alpha$-particle groups corresponding to the 4.43, 7.65, 9.64, 10.85, 11.84, 12.71, 13.29, 14.08, and 15.11 levels in $C^{12}$ were identified. These excitation energies agree with the precise values recently measured with the $B^{10}(He^3,p)C^{12}$ reaction. The appearance of the group leading to the 15.11 level in $C^{12}$ at all these deuteron energies with relative intensities between the 15.11 and 12.71 groups ranging from $1.3\pm0.2$ at a bombarding energy of 5.5 Mev to $0.5\pm0.2$ at 9 Mev indicates a strong violation of the isotopic spin selection rule for the $N^{14}(d,\alpha)C^{12*}$ (15.11 Mev) reaction. These observations have been confirmed and extended by measure-

ments of the 15.1-Mev $\gamma$ rays from a nitrogen target bombarded with deuterons (see following abstract).

* Work supported by the Office of Naval Research, the U. S. Atomic Energy Commission, and the Wisconsin Alumni Research Foundation.

**B11. Yield of 15.1-Mev $\gamma$ Rays from the $N^{14}(d,\alpha)$ Reaction.** I. F. WRIGHT, *University of Wisconsin*, AND C. P. BROWNE, *University of Notre Dame*.*—15.1-Mev $\gamma$ rays have been identified with a 5-in. diam×4-in. NaI crystal placed at 90° to a nitrogen gas target bombarded with deuterons whose energy ranged from 3.5 to 11.5 Mev. These $\gamma$ rays are attributed to the reaction $N^{14}(d,\alpha)C^{12*}$ (15.1 Mev). Their yield has been measured in 100-kev steps from 3.5 to 7.4 Mev with a target ~20 kev thick and shows pronounced peaks at 4.29 and 4.55 Mev (unresolved) and at 5.94 Mev. Preliminary measurements of the yield of the corresponding $\alpha$ particles at 90° (lab.)[1] show that this also has a maximum at ~6 Mev but is small below 5 Mev.

* Work supported by the Office of Naval Research, the U. S. Atomic Energy Commission, and the Wisconsin Alumni Research Foundation.
[1] See preceding abstract.

**B12. Interaction of Deuterons with $O^{16}$.*** R. F. SEILER, C. H. JONES, D. F. HERRING, AND K. W. JONES, *The Ohio State University*.—A differentially pumped gas scattering chamber and solid-state detector have been used to measure absolute cross sections for the elastic deuterons and reaction products produced in the deuteron bombardment of $O^{16}$. Observations were made from 0.67–1.84 Mev with deuterons from The Ohio State University electrostatic accelerator. Excitation curves for the elastic deuterons were measured at center-of-mass angles 90.0°, 125.3°, 140.8°, and 166.2°. An excitation curve for the reaction products was measured at a laboratory angle of 164.2°. The structure observed in the excitation curve for the reaction products was more complex than that observed for the elastic deuterons.

* This work supported in part by the U. S. Atomic Energy Commission and The Ohio State University Development Fund.

**B13. Phase Shift Analysis of $O^{16}(p,p)O^{16}$.** S. R. SALISBURY AND H. T. RICHARDS, *University of Wisconsin*.*—Differential cross sections reported at last year's meeting by S.R.S. *et al.* (plus additional data) have been used for a phase shift analysis. The data were fitted by a least-squares method using an IBM 704. The level parameters were obtained by application of dispersion formalism to the extracted phase shifts. The two level approximation was used where appropriate. The analysis covers the range 2.0–7.6 Mev, except for 4 levels which were too narrow to be resolved. The parameters for each level are listed below in the following order; lab energy in Mev, angular momentum and parity, and ratio of experimental to single particle reduced width. 4.354 ($\frac{3}{2}^-$), 0.027; 4.787 ($\frac{1}{2}^+$), 0.316; 5.231 ($\frac{3}{2}^-$), 0.006; 5.392 ($\frac{5}{2}^-$), 0.022; 5.402 ($\frac{1}{2}^+$), <0.001; 5.546 ($\frac{3}{2}^+$), 0.028; 5.779 ($\frac{1}{2}^-$), 0.002; 6.332 ($\frac{1}{2}^+$), 0.015; 6.483 ($\frac{3}{2}^-$), <0.0001; 6.564 ($\frac{1}{2}^+$), 0.0004; 6.832 ($\frac{3}{2}^-$), 0.0003; 7.180; 7.280; 7.287; 7.305; 7.313 ($\frac{3}{2}^+$), 0.078; 7.385 ($\frac{5}{2}^-$), 0.006.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

**B14. Scattering of Protons by $O^{16}$.** G. HARDIE, R. DANGLE, L. OPPLIGER, F. DEFOREST, AND R. ROTHE, *University of Wisconsin*.*—The elastic scattering of protons on $O^{16}$ was investigated in the energy range of 8.50–13.50 Mev at the center-of-mass scattering angle of 166°52′. Data were taken at 2.5-kev intervals with a 2.5-kev gas target thickness and an energy resolution of several kev. Supplementary investigations were carried out at angles of 28°08′, 54°44′, 76°12′, 90°00′, 109°53′, 122°35′, and 140°46′. The absolute cross sections were measured to within 2%. Over the entire energy range, broad resonance behavior was noted, the widths of the anomalies ranging from about 70 to 200 kev. In addition, two sharp anomalies were observed, one at 12.675 Mev and the other at 13.215 Mev, laboratory proton energy. The laboratory widths are probably less than 5 kev. Detailed angular distributions were taken at selected energies.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

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## FRIDAY MORNING AT 10:00 a.m.

## Eckhart 133

## (R. B. LEACHMAN presiding)

### *Slow Neutrons and Fission*

**C1. Total Neutron Cross Section of $Th^{229}$.*** R. E. COTÉ, H. DIAMOND, AND J. E. GINDLER, *Argonne National Laboratory*.—The Argonne fast chopper has been used to measure the total neutron cross section of $Th^{229}$. Because of the small size of the sample (about 2.4 mg), less than 1% of the normally available beam intensity could be used, a condition that limited the flight path to 25 m and hence the resolution to 0.09 $\mu$sec/m. Furthermore, the results of the measurements are confined to the immediate vicinity of the neutron resonances because of this small available sample of $Th^{229}$. Resonances were observed at 0.608, 1.254, 1.40, 1.71, 1.93, 2.66, 3.15, 4.10, 5.49, 6.89, 9.15, 10.4, 12.5, and 15.2 ev. The discussion of these results will include a comparison between this total cross-sectional measurement and a measurement of the fission cross section[1] which shows resonances at 0.240, 0.563, and 0.727 ev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] V. Y. Konakhovich and M. I. Pevzner, Atomnaya Energ. 8, 47 (1960).

**C2. High Resolution Total Cross-Sectional Measurements on $W^{184}$.** F. A. KHAN,* W. J. GAVIN,‡ AND J. A. HARVEY, *Oak Ridge National Laboratory*.—The ORNL fast chopper and associated equipment were utilized in measuring the transmissions of a sample of normal W and a sample enriched in $W^{184}$ (95%) from 100 to 2000 ev with a resolution of 10 nanosec/m using the 180-m flight path. Data were analyzed on an IBM 7090 computer using an area analysis program[1] which computes the reduced neutron widths for the resonances for assumed total widths. Effects of resolution and Doppler broadening on the line shape were taken into account in computing transmissions which are compared with the experimental transmissions. Resonance parameters, the strength function, and the capture resonance integral of $W^{184}$ will be reported.

* Visiting investigator from Pakistan AEC.
† ORINS summer student trainee.
[1] S. E. Atta and J. A. Harvey (to be published).

**C3. Gamma-Ray Spectra from Neutron Resonances in Platinum.** J. R. BIRD,* *AERE, Harwell* (introduced by J. A. Harvey).—Gamma rays from neutron capture in platinum have been studied using a two crystal pair spectrometer. A 4-in.×1½-in. NaI crystal detected ½ Mev escape quanta from

a 4-in.×4-in.NaI crystal, giving a considerable improvement in line shape and a reduction in peak efficiency of a factor of 15. A 13-m flight path in conjunction with the Harwell linear accelerator determined neutron energies for resonances up to 400 ev. Neutron time of flight and gamma-ray pulse height were recorded on magnetic tape and the results used to give a gamma-ray spectrum for each resonance. Measurements at 90 m were used to indicate which resonances were well isolated. The high-energy end of the gamma-ray spectra were fitted in a least-squares program, using calibrated line shapes for the three highest energy gamma rays, the intensities of which were obtained for each resonance.

* Now visiting Oak Ridge National Laboratory.

**C4. Analysis of Resonance Neutron-Capture γ-Ray Spectra.*** R. T. CARPENTER, J. P. MARION, AND L. M. BOLLINGER, *Argonne National Laboratory.*—Techniques developed for the quantitative analysis of the γ-ray spectra from capture of neutrons in resonances will be described. In the most general case, the γ-ray spectra from all observed resonances in a given nuclide are treated simultaneously. A least-squares fit is performed to obtain the energies of a given number of γ-ray lines (which are the same for all resonances in a given nuclide), the intensities of the transitions (which vary from resonance to resonance), and the statistical errors associated with these quantities. The simultaneous treatment increases the precision of determination of the γ-ray energies. The treatment can be reliably applied to spectral regions in which the lines are partially resolved in any of the resonances. The reference line shapes, which are allowed to depend on the γ-ray energy, are calculated by interpolation between line shapes given to the computer in tabular form for single transitions at various energies. Any physical knowledge of the intensities and energies of any of the lines in the spectra may be fed into the problem as linear constraints. For example, one often knows the difference in energy between at least some of the lines. A $\chi^2$ test of the goodness of fit gives a check on the assumptions used in the calculation. Various special cases of the most general calculation are permitted. The calculations are performed on an IBM-704 digital computer.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**C5. Spin Assignments of Low-Energy Resonances in $Sm^{149}$.*** H. MARSHAK, H. POSTMA, V. L. SAILOR, F. J. SHORE, AND C. A. REYNOLDS, *Brookhaven National Laboratory.*—Using a monoenergetic polarized neutron beam incident on a polarized samarium target, the spins of the first two resonances in $Sm^{149}$ have been measured. The polarized neutron beam is produced by Bragg reflection from a magnetized cobalt-iron crystal. By using one stage of adiabatic demagnetization, polycrystalline samples of samarium ethyl sulfate and samarium double nitrate were cooled to approximately 0.1°K. At this temperature and with the aid of an external magnetic field an appreciable polarization of the samarium nuclei is achieved by making use of the hfs coupling (Gorter-Rose method). Transmission measurements made for the 0.096 and 0.87 ev resonances indicate that the spins are $I+\frac{1}{2}=4$. The spin assignment of the 0.096 ev resonance is in agreement with the results of Roberts *et al.*[1] and Brockhouse.[2] We observed that the direction of polarization of the samarium in the double nitrate sample was the same as that of the ethyl sulfate sample. Separated isotope samples are being prepared to measure the higher energy resonances.

* Work performed under contract with the U. S. Atomic Energy Commission.
[1] L. D. Roberts, S. Bernstein, J. W. T. Dabbs, and C. P. Stanford, Phys. Rev. 95, 105 (1954).
[2] B. N. Brockhouse, Can. J. Phys. 31, 432 (1953).

**C6. Spin-Dependent Neutron Scattering by Polarized Protons.*** R. SCHERMER, H. POSTMA, F. J. SHORE, C. A. REYNOLDS, H. MARSHAK, AND V. L. SAILOR, *Brookhaven National Laboratory.*—Using the apparatus described in the previous paper, we have observed the spin dependence of *n-p* scattering. The experiment consisted of passing a beam of polarized, thermal (0.07 ev) neutrons through a palladium hydride target at a temperature of ~0.07°K. We measured the transmission of the target with the neutron polarization successively parallel and antiparallel to a magnetic field applied to the sample. From the change in transmission between these two cases, we calculatd a proton polarization in the direction of the applied field of $(1.9\pm0.2)\%$ with a field of 17.5 koe and $(0.91\pm0.21)\%$ with a field of 10 koe. With zero applied field or with pure palladium metal, there was no detectable change in transmission. The above polarizations are approximately 75% of the expected "brute force" values, and it is impossible to distinguish between the two possible pairs of *n-p* scattering lengths in his experiment. However, the two possible pairs of *n-d* scattering lengths lead to opposite signs for the parallel-antiparallel transmission difference. We are planning to perform the "polarized dueteron" experiment in the near future.

* Work performed under contract with the U. S. Atomic Energy Commission.

**C7. Utilization of the $Bi^{210}$ Reaction for Polonium Production.** F. L. BOUQUET, JR., *Lockheed-California Company.*—Calculated results of a systematic study of the production of polonium-210 using neutron capture in bismuth will be discussed. The calculations were performed on an IBM-7090 computer. The best values for neutron capture cross section for bismuth which were produced by the survey are the following:

| Element | Energy | 0.025 ev | 25 kev | 14.0 Mev |
|---|---|---|---|---|
| $Bi^{209}$ | Capture cross section | 32 ±2 mb[1] | 1.8 mb[2] | 1.2 mb[3] |

Consideration of other competitive reactions, such as $(n,n'\gamma)$ and $(n,2n)$, were also included. The various methods of $Po^{210}$ production were examined using the above cross sections. Preliminary results indicate that the maximum concentrations are achievable with, in order of importance, thermonuclear explosions, nuclear reactors, Phillips tube, and Po-Be-type neutron sources.

[1] *American Institute of Physics Handbook* (McGraw-Hill Book Company, Inc., New York, 1957), p. 8–168.
[2] UCRL Report 5226 (Rev), Pt. I, Vol. III (1959).
[3] Private communication with Lawrence Radiation Laboratory.

**C8. Spontaneous Ternary Fission of $Cf^{252}$, $Cm^{244}$ and $Cm^{242}$.*** D. J. HENDERSON, H. DIAMOND, AND T. H. BRAID, *Argonne National Laboratory.*—The frequency and energy of long-range alpha particles in coincidence with spontaneous fission were measured with surface barrier silicon detectors and CsI crystal detectors. The spectrum of long-range alphas from $Cf^{252}$ has a peak at 15.5 Mev. Its full width at half-maximum is 13 Mev. $Cf^{252}$ emitted one long-range alpha above 9.8 Mev per 312±17 fissions. $Cm^{244}$ emitted one long-range alpha above 11.6 Mev per 273±57 fissions. $Cm^{242}$ emitted one long-range alpha above 10.6 Mev per 978±210 fissions.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

**C9. Helium-Ion-Induced Fission of Bi, Pb, Tl, and Au.*** J. R. HUIZENGA, R. CHAUDHRY,† AND R. VANDENBOSCH, *Argonne National Laboratory.*—The fission cross section for helium-ion-induced fission of bismuth, $Pb^{206}$, thallium, and gold have been measured with solid-state detectors as a function of bombarding energy. The fission cross section of the above targets with 42.8-Mev helium ions are 7.3, 1.8, 0.65, and 0.28 mb, respectively, and the cross sections decrease rapidly with reduced energy projectiles. The competition between fission

and neutron emission as a function of excitation energy is compared with theoretical predictions of $\Gamma_f/\Gamma_n$. From such comparisons fission thresholds for $At^{213}$, $Po^{210}$, $Bi^{209}$, and $Tl^{201}$ are derived of 15.8±2.0, 18.6±2.0, 20.6±2.0, and 19.9±2.0 Mev, respectively. The saddle point mass surface of these nuclei relative to a reference mass surface lies on a smooth curve with the heavy element data indicating that the shell structure is completely destroyed during the distortion from the equilibrium to the saddle deformation. An empirical equation for fission thresholds is deduced which is thought to be valid for nuclei with $Z^2/A \geq 32.5$.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from Atomic Energy Establishment, Trombay, India, under sponsorship of the International Cooperation Administration.

**C10. Angular Distribution of Fission Fragments from Helium-Ion-Induced Fission of Bi, Pb, Tl, and Au.*** R. CHAUDHRY,† R. VANDENBOSCH, AND J. R. HUIZENGA, *Argonne National Laboratory.*—The $W(174.5°)/W(90°)$ ratios for 42.8-Mev helium-ion-induced fission of bismuth, lead, $Pb^{206}$, thallium, and gold are 2.26±0.07, 2.47±0.08, 2.46±0.08, 2.53±0.08, and 2.62±0.08, respectively. The energy dependence of $K_0$, deduced from the experimental anisotropy measurements as a function of helium-ion energy, is similar to the predicted energy dependence from statistical theory if the nuclear temperature at the saddle point is proportional to the square root of the excitation energy. These results indicate that the effective moment of inertia at the saddle point is independent of excitation energy, in contrast with the heavy element (uranium region) results. With the assumption that the effective moment of inertia at the saddle point for the highest excitation energy is the rigid-body value, the stretching at the saddle point is calculated for various simple geometric configurations. For example, if the saddle point is represented by two equal tangent prolate spheroids, the ratios of the major to minor axes $(C/A)$ for the fissioning nuclei $At^{213}$, $Po^{210}$, $Bi^{209}$, and $Tl^{201}$ are 1.30, 1.52, 1.67, and 1.82, respectively. Furthermore, if the symmetric scission point is assumed to have the same configuration, the value of $(C/A)$ at the time of scission which is derived from kinetic energy measurements is 2.24 for all nuclei, consistent with the empirical relation, $E_K = 0.121\ Z^2/A^{\frac{1}{3}}$.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from Atomic Energy Establishment, Trombay, India, under sponsorship of the International Cooperation Administration.

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## FRIDAY MORNING AT 10:00 a.m.

## Judd 126

(D. D. LAZARUS presiding)

### *Defects and Radiation Damage*

**D1. Interstitial Motion near 40°K in Copper.*** A. V. GRANATO, *University of Illinois,* AND T. G. NILAN, *Applied Research Laboratory, U. S. Steel Corporation.*—An analysis of annealing kinetics for recombination of interstitials with vacancies has been made. This shows that "close pair" annihilation should follow first-order kinetics, interstitial-vacancy recombination through the motion of the interstitial in three dimensions should follow second-order kintics, but recombination resulting from one-dimensional (crowdion) motion of the interstitial should follow third-order kinetics. The rate at which annealing occurs has a maximum, whose location depends upon the acitvation energy, number of jumps to annihilation, and warming rate. The shift of the position of the maximum with concentration of defects depends upon the annealing kinetics. It is greatest for third-order, intermediate for second-order, and zero for first-order kinetics. A comparison of the calculated peak shifts with the electron radiation experiments of Corbett, Smith, and Walker[1] shows that the data is consistent with three-dimensional motion of the interstitial but is inconsistent with one-dimensional motion. The argument does not depend on the magnitude of the number of jumps made by the interstitial.

* Supported by the U. S. Atomic Energy Commission.
[1] J. W. Corbett, R. B. Smith, and R. M. Walker, Phys. Rev. 114, 1460 (1959).

**D2. Annealing of Quenched Silver.*** M. DOYAMA AND J. S. KOEHLER, *Department of Physics, University of Illinois.*—99.999% pure silver was quenched from temperatures between 450°C and 850°C. A defect migrating with an energy of motion of 0.57 ev is observed to anneal in the range from −50°C to +150°C. If the annealing is done below 0°C a second-order process is found. On annealing above 100°C the annealing is nearly first order with the same activation energy. Pulsing a quenched wire to 300°C for $\frac{1}{15}$ sec produces a defect which anneals with a migration energy which is 0.83±0.07 ev. This is probably the lattice vacancy. The binding energy of the defect which produces vacancies on breakup is 0.35±0.08 ev. The identity of the defect which migrates with energy 0.57 ev will be discussed.

* Research supported by U. S. Army Research Office, Durham, North Carolina.

**D3. On the Existence of "Structural Expansion" and "Structural Defect" Production during Isothermal Annealing of Heated Gold.*** R. O. SIMMONS AND R. W. BALLUFFI, *University of Illinois.*—Åström has reported[1] heat absorption in high-purity silver, gold, aluminum, and molybdenum, and expansion in gold during isothermal annealing immediately following heating (≤100°C/min) to temperatures $T_m$ in the range 433 to 753°K. The relative linear expansion in gold was claimed to be $\Delta L/L \simeq (1.6\times10^{-3})\times\exp[(-0.26\pm0.08)\text{ev}/kT_m]\exp(-t/\tau)$, where $\tau$ was 2–3 hr, similar to the time constant given by the calorimetric work. These results were experimentally inconsistent with the production of thermal vacancies or other currently recognized lattice defects, or with the dissolution of precipitates; they were therefore tentatively explained[1] in terms of the "structural defects" having similar formation energies postulated in the phenomenological analyses of G. Borelius. For such structural defects one would expect $\Delta L/L = \Delta a/a$,[2] where $a$ is the x-ray lattice parameter, and, therefore, in the present similar experiments $\Delta a/a$ has been measured in an attempt to verify the existence of "structural expansion." A rapid x-ray technique was used on a 99.999% gold crystal at $T_m$=750 and 850°K for which Åström predicts total expansions of $31\times10^{-6}$ and $49\times10^{-6}$, respectively. The shortest time studied was 5 min and the mean

precision for 102 measurements of $\Delta a/a$ was $4\times10^{-6}$. No detectable trace of the claimed expansion was found.

* Work supported by the U. S. Atomic Energy Commission.
[1] H. U. Aström, Arkiv Fysik 14, 263 (1959); 18, 465 (1961).
[2] R. W. Balluffi and R. O. Simmons, J. Appl. Phys. 31, 2284 (1960).

**D4. Pressure and Temperature Dependence of Creep in Sodium.*** A. L. RUOFF,† R. H. CORNISH, AND B. M. BUTCHER, *Cornell University.*—Steady-state creep sodium was measured for strain rates of $10^{-9}$ to $10^{-4}$ sec$^{-1}$, pressures of 1–10 000 bars, temperatures of $-20°$ to $+90°$ C, and tensile stresses of 0.1 to 1.0 bars. For strain rates below $3\times10^{-7}$ sec$^{-1}$ the values obtained for the activation energy for creep, $E_c$, by the method of rapidly changing the temperature, and for the activation volume $V_c$, by rapidly changing the hydrostatic pressure are $E_c=0.44$ ev, $V_c=0.53\Omega_0$. Results obtained for self-diffusion by tracer methods by Nachtrieb *et al.* are: $E_d=0.45$ ev, $V_d=0.52\Omega_0$. For slow strain rates the data is consistent with a rate-controlling mechanism involving diffusion of vacancies to jogs in dislocations. However, for strain rates above $3\times10^{-7}$ sec$^{-1}$ (obtained by increasing *either* stress or temperature) the results are: $(E_c)=0.88$ ev, $(V_c)=1.04\Omega_0$. For the faster strain rates, half of the jogs apparently act as interstitial sources instead of as vacancy sinks as they do for the slower creep rate. The values of $(E_c)$ and $(V_d)$ are consistent with values estimated for diffusion of sodium interstitial atoms.

† Visiting Professor, University of Illinois, 1961-1962.
* Work supported by the U. S. Atomic Energy Commission and in a lesser part by the Advanced Research Projects Agency.

**D5. Vacancy Supersaturation During Quenching in Ge and Si.** J. MELNGAILIS AND S. O'HARA, *Westinghouse Research Laboratories.*—When a solid is rapidly cooled from a high temperature, an excess concentration of vacancies may be trapped in its interior.[1] The diffusion of vacancies during quenching from the melting point is examined mathematically for Ge and Si. In dendrites of 0.01-cm thickness of either material, under average conditions, approximately $10^{-3}$ $\phi_0$ vacancies per cm$^3$ would be trapped during cooling after growth, where $\phi_0$ is the equilibrium concentration at the melting point. For radiation quenched samples of larger dimensions[2] (approx 1 mm), the concentration trapped with surfaces acting as sinks is $\frac{1}{3}$ $\phi_0$ to $\frac{2}{3}$ $\phi_0$, but with $6\times10^4$ dislocations per cm$^3$ acting as sinks only $10^{-4}$ $\phi_0$ to $2\times10^{-3}$ $\phi_0$ are trapped. Existing theory[3] combined with the present calculation indicates that the formation of disolcation loops in growing dendrites of Ge is unlikely.

[1] For general review and bibliography see H. Letaw, J. Phys. Chem. Solids 1, 117 (1956).
[2] S. Mayburg, Acta Met. 4, 52 (1956).
[3] C. Elbaum, Phil. Mag. 5, 669 (1960).

**D6. Thermal and Chemical Bleaching of *F*-Centers in KCl.*** J. C. PENLEY† AND R. S. WITTE, *University of Notre Dame.*—The rate of thermal conversion of *F* centers to colloid centers in additively colored KCl has been studied in an effort to determine the mechanism of precipitation of the excess potassium. The time dependence of the concentration of *F* centers was found to follow an equation of the form $c(t)=c(t=0)\exp-(t/\tau)^n$ where $n$ had the values of $\frac{2}{3}$, 1, or $\frac{1}{2}$. In the majority of crystals studied, the best fit was obtained with $n=\frac{1}{2}$. Accordingly, it is believed that the precipitation of the excess potassium is best described as a dislocation induced process in which *F* centers diffuse to the dislocations where they combine with lattice potassium ions to form colloidal potassium. Crystals heated in the presence of water vapor developed a colorless surface region. Study of the motion of the boundary between this clear region and the colored interior as a function of temperature led to an activation energy of $13.0\pm1.7$ kcal/mole. This energy is associated with the diffusion of water into the crystal.

* Supported in part by the National Science Foundation.
† Recipient of a U. S. Rubber Company Fellowship.

**D7. Characteristics and Annealing of Neutron Irradiated PbTe.** J. C. CORELLI AND D. M. AMOROSI, *Knolls Atomic Power Laboratory.**—Conductivity and Seebeck and Hall coefficient changes of *n*- and *p*-type PbTe were measured after reactor irradiation of $1–10\times10^{19}$ cm$^{-2}$ of neutrons with energy greater than 1 Mev and thermal neutron doses of $10^{20}–10^{21}$ cm$^{-2}$. Isothermal annealing experiments indicate simultaneous recovery of conductivity, Hall and Seebeck coefficient in the temperature ranges 100–170°C and 140–180°C for *p*- and *n*-type materials, respectively. The carrier concentration decrease for both materials (factor 5) accounts for nearly the entire increase in Seebeck coefficients (factor 2). Analysis of the annealing of conductivity (increased by factor 17) for the *p*-type PbTe data yields an activation energy of $1.3\pm0.1$ ev. For *n*-type PbTe, analysis of both conductivity increased by factor 12) and Hall coefficient yields an activation energy of $1.3\pm0.1$ ev, and the depression of the carrier concentration can be attributed to a bombardment-induced trapping level 0.026 ev below the bottom of the conduction band. In both materials there is evidence of a second stage in the annealing process. Subsequent to annealing both materials retain their characteristic intrinsic gaps of $\approx0.32$ ev, and the mobility of *n*-type PbTe exhibits a $T^{-1}$ variation. Small permanent changes due to transmutations, and comparisons with previous irradiations at lower doses will be discussed.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

**D8. Expansion of InSb upon Low-Temperature Electron Irradiation.*** FREDERICK L. VOOK, *Sandia Laboratory.*—Precision measurements of the change in length of high-purity, single-crystal InSb were made upon irradiation and annealing. The sample was initially irradiated below 110°K to an integrated flux of $2.0\times10^{19}$ electron/cm$^2$. The specific length expansion was $\Delta L/L=1.0\pm0.1\times10^{-23}$ per 2-Mev electron. The sample was then warmed from 50° to 330°K at 10°K/hr. Between 50° and 170°K the sample expanded further in a reverse annealing. Above 290°K the expansion recovered as for a normal anneal. Further irradiation at <175°K with 1.4 Mev electrons to an integrated flux of $1.8\times10^{19}$ electron/cm$^2$ yielded an expansion rate which was smaller than that for 2.0 Mev electrons by a factor of 4.5. The ratio of the two expansion slopes yields a threshold displacement energy of 30 ev in good agreement with Aukerman's carrier removal data, but in disagreement with Eisen's value of 7 ev. The curious, length-annealing behavior is very similar to the annealing of carrier concentration in *p*-type InSb observed by Aukerman. The expansion of InSb is much larger than previous measurements on germanium and silicon and is attributed to the partly ionic nature of the bonding. The expansion observed here for electron irradiation is in contrast to the contraction observed by Gonser and Okkerse for deuteron bombardment.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 10:00 a.m.

Social Sciences 122

(J. J. BROPHY presiding)

## *Electron Emission from Surfaces*

**E1. Electron Emission from Inhomogeneous Surfaces.** B. J. WEIGMAN, JR., *Loyola College*, AND J. L. GUMNICK, *RIAS.*—The fact that electrons are not emitted uniformly from an inhomogeneous or patchy surface has been reported in the literature. By assuming that real surfaces are made up of a number of ideal surfaces each with a different work function after the manner of Herring and Nichols, a distribution function has been written describing the relationship between electron emission and measurable properties of the surface. The meaning of experimentally measured work functions and Richardson $A$ numbers is discussed in light of the various work functions represented on any real surface. A Richardson-type equation is written which includes emission from all patches. All work functions from a lowest value $\phi$ min to a highest value $\phi$ max are given representation according to a distribution function $f_i$. The function $f_i$ is the fractional area having a work function $\phi_i$. The difference in work function $\Delta\phi_i$ between patches $\phi_i$ and $\phi_{i+1}$ is assumed to be discrete rather than continuous. This difference can be varied according to the homogeneity of the surface. The distribution function $f_i$ will be zero for those patches not represented. Several distribution functions are considered. The $A$ number and the average work function depend markedly upon the distribution of patches. Possible methods of determining the function $f_i$ experimentally are discussed.

**E2. Emission Fields, Workfunctions, Ionization Potentials, and Normal Cathode Falls of Potential—Empirical Relations.** HERMAN RITOW, *Research Engineer, Highland Park, Illinois.*—For more than forty years, scientific observations have been noted of the near proportionality between work functions and cathode falls of potential Study of these leads to a number of empirical relations among gas discharge parameters. These relations in the light of the ionic condenser theory[1] make it possible to compute critical emission fields not previously found, to improve the accuracy of known emission fields, and to pinpoint some parameter inaccuracies published in standard handbooks. The relations also point the way towards simpler and more certain methods of measurement of the critical emission fields. Each determination of a work function or of an ionization potential can be used to measure a critical emission field.

[1] H. Ritow, J. of Electronics and Control **4**, 97, 111 (1958); **5**, 193 (1959); **6**, 236 (1959); **7**, 423 (1959).

**E3. Work Function and Photoelectric Threshold for Atomically Clean Silicon.** F. G. ALLEN AND G. W. GOBELI, *Bell Telephone Laboratories, Inc.*—The true work function and photoelectric yield of silicon (111) surfaces freshly cleaved in a vacuum of $10^{-10}$ mm Hg have been measured over a wide range of bulk doping. The work function varies only from 4.90 ev for 0.002 ohm cm $p$ type to 4.76 ev for 0.0015 ohm cm $n$ type. For all but low-resistivity $n$-type samples, photoemission from the valence band dominates, so that the photoelectric threshold is the energy difference between the vacuum level and the top of the valence band. This is found to be ~5.1 ev. This threshold can be measured accurately only for a range of resistivities near the flat band condition (high resistivity $p$ type) where space charge band bending is small over the escape depth of photoelectrons. For both extreme $p$- and $n$-type material, strongly bent bands shift the apparent threshold, which then approaches the true work function in both cases, for different reasons. Surface state densities and distributions required to explain the observed surface Fermi level location and its insensitivity to bulk doping are discussed.

**E4. Photoelectric Yield from Atomically Clean Silicon.** G. W. GOBELI AND F. G. ALLEN, *Bell Telephone Laboratories, Inc.*—The characteristic photoelectric yield spectrum from atomically clean (111) silicon surfaces has been examined as a function of sample doping and has been compared with clean single crystal tungsten. The yield increases and the spectral shape changes as the doping changes from $n$ to $p$ type. It is concluded that photoelectrons originate at depths comparable to the space charge layer for lower resistivity samples. This yield dependence on doping indicates that the photoelectric emission occurs as a result of a volume process. Two excitation mechanisms are involved: (1) indirect phonon assisted transitions and (2) direct optical transitions into final states lying above the vacuum level. The yield spectrum for a sample with bands flat up to the surface (high resistivity $p$ type) should show a discontinuity as the threshold for direct transitions is exceeded and the more efficient process dominates. A discontinuity in the yield spectrum at 5.45 ev, the analysis of the spectral shape, the dependence of yield on sample doping, and the effects of gas adsorption are consistent with this interpretation. Analysis of direct photoelectron emission is discussed.

**E5. Experimental Measurements of Work Function and Richardson Number Relationships for Rhenium.** G. J. DALY AND J. L. GUMNICK, *RIAS.*—Thermionic emission constants for rhenium have been measured. The measurements were taken using a guard-ring diode with a directly heated 10-mil diam rhenium wire for a cathode and Aqua-dag coated glass as anode and guard rings. Seventeen determinations of the work function and Richardson $A$ number were made using both Schottky and saturation-current methods. Work function values $\phi$ varied from 4.15–5.26 ev. Richardson $A$ numbers ranged from 2.14 amp/cm$^2$ deg K$^2$ to 730 amp/cm$^2$ deg K$^2$. The measured $A$ and $\phi$ values were such that a plot of ln $A$ vs $\phi$ was linear over the range of values obtained. Other determinations of $A$ and $\phi$ for rhenium reported in the literature fall on the same straight line. From the ln $A$ vs $\phi$ plot, the work function of rhenium associated with an $A$ number of 120 amp/cm$^2$ deg K$^2$ was 4.95 ev.

**E6. Cyclic Migration of Cesium on Rhenium Observed Using the Field Emission Microscope.** J. L. GUMNICK AND G. J. DALY, *RIAS.*—Studies of the behavior of cesium deposited on a rhenium point have been made using a field emission microscope. Deposition was carried out after measurements were made on the clean rhenium point. Several monolayers were deposited on the rhenium at room temperature and resulted in a change in emission characteristics from $1\times10^{-7}$ amp at 15 000 v to $700\times10^{-7}$ amp at 3000 v. There was no radical change in the emission pattern other than an increased relative brightness of the originally low work function planes. At voltages between 2800 and 3800 v, migration of cesium was observed starting from the high emission regions of the point. The migration was roughly of a circular shape moving concentrically to the edges of the emission pattern. After a time lapse of several seconds, migration proceeded from the outside of the pattern back to the original configuration. The process repeated itself in cycles with periods of the order of 8 sec. Associated with the migration were changes in

emission current from ~10 μamp to ~50 μamp. The shape of current versus time wave forms of the cyclic activity were almost identical over periods of a few minutes but showed slight continuous changes over longer periods of time. Photographs of the process have been taken and have been correlated to plots of the current-time fluctuations of field emission current. A possible mechanism for the cyclic migration will be described.

**E7. Kinetics of Strontium Oxide on Molybdenum by Field Electron Microscopy.*** D. R. MORGAN AND E. A. COOMES, *University of Notre Dame.*—Kinetics of strontium oxide on molybdenum have been studied by field electron microscopy in the range 1000°–1830°K. Activation energies were measured by studying pattern changes as a function of time at constant temperature. Reaction of SrO on Mo at 1135°K results in the field emission pattern that has tentatively been identified as the basic molybdate. Between 1135° and 1400°K, the basic molybdate apparently goes over to the normal molybdate with an activation energy of ~43 kcal. Cluster formation on the edges of the {111} region and an inversion in symmetry in the {100} pattern are associated with this process. The average Fowler-Nordheim work function reaches a minimum as the {100} symmetry inversion occurs. Above 1400°K, decomposition of the normal molybdate occurs. This is suggested by the fact that patterns in this range are similar to patterns which were obtained for oxygen on Mo. Desorption, ending in the clean Mo pattern, occurs above 1600°K with an activation energy of ~124 kcal.

* Supported in part by the Office of Naval Research.

**E8. Photoemission from Thin Films of Strontium and Barium Oxides on Molybdenum.*** J. L. SHILTS AND D. W. JUENKER, *University of Notre Dame.*—The spectral distribution of the photoelectric yield from a polycrystalline molybdenum ribbon coated with films of SrO and BaO have been measured for wavelengths from 226–620 mμ. The films were evaporated onto the cathode at room temperature in thicknesses from zero to roughly a hundred layers. As the film thickness was increased, the threshold energy estimated by the Fowler method decreased from the value for clean molybdenum, passed through a minimum, and then increased slightly before the yield curve assumed nonmetallic characteristics. The minimum threshold found in the case of SrO films was 1.9 ev; for BaO it was 1.7 ev. Under these conditions, the experimental yields deviated only slightly from Fowler theory as far as 3.7 ev from the threshold. The height of the distribution curve, related to the Fowler coefficient, exhibits a maximum at the threshold minimum. Spectral distribution curves from thick films of evaporated BaO resembled those found previously[1] from sprayed coatings.

* Partially supported by the U. S. Atomic Energy Commission.
[1] H. R. Philipp, Phys. Rev. 107, 687 (1957).

**E9. Thermionic Emission from Single Crystal Molybdenum Wire.*** G. GARDNER, R. L. ANTHONY, AND E. A. COOMES, *University of Notre Dame.*—An improved electron projection tube with an aluminum-backed screen was used to study thermionic emission from molybdenum single crystals having [110]'s aligned with the wire axis. The crystals were grown by the torsion technique.[1] Richardson work functions obtained by a photometric method were similar to those reported by Smith[2] for tungsten. The highest work function obtained was 4.9±0.1 ev for the ⟨110⟩ and the lowest was 4.3±0.1 ev in the case of the ⟨116-114⟩. Emission maxima found in the center of the {112} and {001} indicate possible double faceting on these areas. Photomicrographs show plateau-like structures on the {110}, {112}, and {001}.

* Supported in part by ONR and USAF.
[1] Gifford and E. A. Coomes, J. Appl. Phys. 31, 235 (1960).
[2] G. F. Smith, Phys. Rev. 94, 295 (1954).

**E10. Thermionic Emission from Single Crystal Tungsten Wire with [110] Inclined to Wire Axis.*** R. L. ANTHONY, G. GARDNER, AND E. A. COOMES, *University of Notre Dame.*—The projection tube technique mentioned in the preceding abstract was used to study thermionic emission from two tungsten single crystals adjacent to each other in the same 5-mil filament. For one crystal, the [110] was inclined 11 deg to the wire axis; the other crystal had the [110] inclined 27 deg. The crystals grew in this modification as a result of annealing in high vacuum for 15 hr at 1960°K. The emission versus azimuth plot for the 11-deg crystal was similar to that of Nichols and Smith.[1] In the case of the 27-deg crystal, the symmetry of the pattern was different. The highest Richardson work functions determined for the two crystals were 4.8±0.1 and 4.7±0.1 ev, respectively. These values corresponded to deep minima diametrically opposite each other in the emission patterns, and near to the ⟨110⟩.

* Supported in part by ONR and USAF.
[1] G. F. Smith, Phys. Rev. 94, 295 (1954).

**E11. Electron Emission Characteristics of a Model Cylindrical Crystal.*** D. W. JUENKER, G. GARDNER, R. C. JAKLEVIC, AND A. J. QUIGLEY, *University of Notre Dame.*—Results are given from a computational analysis of the electron emission properties of a model cylindrical crystal. The model has a smooth azimuthal variation of work function with the symmetry proper to a cubic 110 axial orientation and is distinctly tungsten-like, being patterned after the values of work function at various crystal directions obtained for that metal by Müller[1] and by Smith.[2] The following features of the model have been examined: the local motive shape, the thermionic Schottky behavior and patch effect in representative crystal directions, the thermionic and photoelectric Schottky behavior of the entire cylinder, the influence of the work function nonuniformity on the apparent emission constants, the effect of electron scattering from a collecting electrode on emission measurements, and the influence of such scattering on the Richardson determination of the thermionic constants for regions of the emitter having very high work function.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] E. W. Müller, J. Appl. Phys. 26, 732 (1955).
[2] G. F. Smith, Phys. Rev. 94, 295 (1955).

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## FRIDAY MORNING AT 9:30 a.m.

## Rosenwald 2

## (S. K. ALLISON presiding)

### *General Physics*

**F1. Scattering of Thermal Rare Gas Beams by Argon.*** ERHARD W. ROTHE, LAWRENCE L. MARINO, R. H. NEYNABER, AND S. M. TRUJILLO, *Convair.*—Total cross sections have been measured for the scattering of atomic beams of He, Ne, Ar, Kr, and Xe by argon. A modulated beam technique was employed. The apparatus had an angular resolution of 1.5 min of arc. The

data were correlated using the Massey-Mohr theory,[1] assuming an attractive interatomic potential $V(r) = -C/r^6$, in which case the cross section $Q$ is given by $Q = b(C/v)^{2/5}$, where $b$ is a constant and $v$ is the relative velocity. Values of $C$ may also be estimated from theoretical expressions and from experimental data on transport properties in gases. By using these sources for $C$, we may calculate $Q$. The cross sections obtained from our experiment were higher than the Massey-Mohr theory predicts. For the argon-argon interaction, for example, a theoretical expression for $C$ (that of Kirkwood and Müller) indicates that $Q = 410$ A². From viscosity data we infer that $Q$ should be 383 A². The experimental value is 471 A². The discrepancy is beyond experimental error.

* Supported in part by the Advanced Research Projects Agency (Project Defender) through the Army Rocket and Guided Missile Agency.
[1] H. S. W. Massey and C. B. O. Mohr, Proc. Roy. Soc. (London) **A144**, 188 (1934).
[2] K. S. Pitzer, Advances in Chem. Phys. **2**, 59 (1959).

**F2. Proton Measurements near the Peak of the Inner Van Allen Belt.*** R. V. SMITH, P. C. FISHER, W. L. IMHOF, R.D. MOFFAT, D. D. ELLIOTT,† AND F. S. MOZER,† *Lockheed Missiles and Space Company Research Laboratories.*—A measurement of the high-energy proton flux in the inner belt has been made at an altitude of 2000 miles on a satellite with a polar orbit. The detectors consist of two scintillation counters having proton thresholds at about 60 Mev and 120 Mev provided by their shield thickness and a geiger counter with a proton shield thickness of 60 Mev. The counting rate of each detector was determined from the telemetered output of a logarithmic count rate meter. A southward pass over the Pacific shows the latitude dependence of the proton flux and indicates, within 20 degrees of the magnetic equator, a higher flux than had been expected. Comparison of the geiger counter and 60-Mev scintillator rates indicates that the particles being counted are predominately protons. Comparison of the 60-Mev and 120-Mev scintiliator rates yields a steep proton spectrum. The spectrum and its variation with latitude will be discussed.

* Work supported by the U. S. Air Force.
† Now at Aerospace Corporation.

**F3. On Recent Results of Ballistic Re-Entry.** W. H. T. LOH, *Chance Vought Corporation.*—The fundamental equations for ballistic re-entry are unsolvable analytically. However, at large initial angles of inclination where the angle of inclination may be treated as a constant along the trajectory, approximate analytical solutions were obtained recently.[1-3] Large initial angles of inclination result in large missile deceleration and large aerodynamic heating. Both large deceleration and large aerodynamic heating are usually intolerable for ballistic entry. Therefore, it is always desirable to have ballistic entry at small initial angles of inclination. The solution at small initial angles of inclination can, so far, only be solved by numerical machine computations. It is the purpose of this paper to present, briefly, several recent analytical solutions, some already presented in June[4] and August[5] this year and some not presented before, of ballistic entry which are valid for small initial angles of inclination as well as for large initial angles of inclination.

[1] Carl Gazley, Rand rept. P-955 (1957).
[2] Allen and Eggers, NACA TN 4047 (1957).
[3] W. H. T. Loh, J. Aero/Space Sci. **27**, 10 (1960).
[4] W. H. T. Loh, IAS preprint 61-116-1810 (1961).
[5] W. H. T. Loh, AAS San Francisco meeting (August, 1961).

**F4. Continuum Radiation from Ionized Rare Gases in Reflected Shock Waves.*** FREDERICK H. MIES,† *Brown University.*—Observations have been made of the temperature, pressure, and frequency dependences of the visible and ultraviolet continuum radiation emitted by the ionized rare gases Ar, Kr, and Xe. The plasmas, whose continua are generally attributed to the radiative recombination of free electrons and ions, have been formed in reflected shock waves in which the equilibrium temperatures range from 7500 to 12 000°K and the electron densities range from $10^{15}$ to $10^{18}$ cm$^{-3}$. Some distance behind the reflected shock wave, a region is found which possesses the predicted shock properties and in which the intensity of the continuum radiation attains a steady-state value. This steady state intensity has been examined at seven wavelengths from 2451 to 4800 A, and in addition the ratio of the Kr continuum to the 4319.6 A Kr line intensity has been observed. The continuum intensity is shown to be proportional to the electron density squared and essentially independent of the ion involved. The observed $e^{-h\nu/kT}$ decay of the continuum intensity in the ultraviolet, together with the total temperature dependence and the measured absolute intensity of the continuum, demonstrates that the continuum originates from radiative recombination. The expected temperature and pressure behavior is also found for the Kr line emission, which has an observed oscillator strength of 0.01.

* Supported in part by the U. S. Air Force.
† Present address: National Bureau of Standards, Washington, D. C.

**F5. Low-Energy Continuous X-Ray Spectrum: Dependence of Intensity on Target Potential.*** T. J. PETERSON, JR., AND D. H. TOMBOULIAN, *Cornell University.*—As a continuation of previous measurements[1] the energy radiated in the continuous spectrum has been studied with a photon counting spectrometer[2] using a Cu-Be electron multiplier as detector. The photomultiplier was positioned to cover the wavelength band from 173 A to 193 A. Photon counts were obtained from freshly evaporated magnesium and manganese at potentials ranging from 450 to 900 v. The experimental data are in reasonably good agreement with the numerical predictions[3] of the basic Sommerfeld theory.

* Research supported by U. S. Army Research Office, Durham, North Carolina.
[1] T. J. Peterson, Jr. and D. H. Tomboulian, Bull. Am. Phys. Soc. **6**, 284 (1961); results to be published in Phys. Rev.
[2] D. E. Bedo and D. H. Tomboulian, Rev. Sci. Instr. **32**, 184 (1961).
[3] P. Kirkpatrick and L. Wiedmann, Phys. Rev. **67**, 321 (1945).

**F6. Continuous Photoelectric Absorption Cross Section of Helium.*** D. J. BAKER, D. E. BEDO, AND D. H. TOMBOULIAN, *Cornell University.*—The continuous photoelectric absorption cross section was determined in the spectral range extending from 180 A to 600 A. A single measurement at 180 A was made using a grazing incidence spectrometer equipped with a photomultiplier. The remaining data were obtained in a normal incidence spectrometer by the method of photographic photometry. Whereas in previous experiments the sample of absorbing gas was allowed to fill the entire spectrometer, the present measurements were carried out by the use of a gas absorption cell described previously.[1] With a cell, gas pressures may be controlled and measured more reliably. Furthermore, the possibility of contamination is reduced and the operation of source and detector is not disturbed. The cross section is found to vary from $0.98 \pm 0.04$ mb at 180 A to $7.7 \pm 0.3$ mb at the absorption edge located at 504 A. The results will be compared with other measurements. The observations are found to be in good agreement with recent theoretical calculations.[2,3]

* Research supported by the Office of Naval Research.
[1] D. L. Ederer, D. J. Baker, and D. E. Bedo, Bull. Am. Phys. Soc. **6**, 482 (1961).
[2] S. Huang, Astrophys. J. **108**, 354 (1948).
[3] A. L. Stewart and W. J. Wilkinson, Proc. Phys. Soc. (London) **75**, 796 (1960).

**F7. Polarization of Light Resulting from the Excitation of Helium by Electrons.*** R. H. MCFARLAND AND E. A. SOLTYSIK, *Lawrence Radiation Laboratory.*—Observations have been made on the polarization of light resulting from the excitation of helium by electrons. The wavelength of the light was analyzed with a Bausch and Lomb monochrometer, and the polarization of the emitted light was analyzed with a KN 36 polaroid sheet. The polarization of the following lines has been

measured as a function of the energy of the bombarding electrons: $\lambda=3888$, $\lambda=5015$, and $\lambda=4921$. An axial magnetic field was applied parallel to the electron beam, and the dependence of the polarization of the light on the field strength was observed. In addition, observations were made at different helium gas pressures.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**F8. Characteristics of Low Energy Solar Cosmic Rays as Revealed by Cosmic Noise Absorption Observations in Polar Regions.** W. R. WEBBER, *University of Minnesota* (introduced by J. R. Winckler).—The absorption of cosmic radio noise in the lower ionosphere in polar regions as a result of increased ionization from solar cosmic rays is discussed. Electron production rates as a function of latitude and altitude for different intensities and spectra of solar cosmic rays incident on the ionosphere are presented. Following a discussion of the translation of these electron production rates into radio wave absorption coefficients, particle intensities calculated in this way are compared with actual measurements using other techniques during solar cosmic-ray events. In particular, certain characteristics of the low-energy particles during the April 1, May 4, September 3, and November 12 and 15, 1960, solar cosmic-ray events are discussed. A detailed picture of the geomagnetic thresholds existing during the course of these events is also presented. And finally, a sweep-frequency technique for studying cosmic rays with cosmic noise absorption techniques is suggested. With such a method, it should be possible to increase the sensitivity of such detection methods by ~50 times and also to measure the differential spectrum of particles incident on the ionosphere above a single detector.

**F9. Improved Upper Limit for the Anisotropy of Inertial Mass from a Nuclear Magnetic Resonance Experiment.*** V. BELTRAN-LOPEZ, H. G. ROBINSON, AND V. W. HUGHES, *Yale University*.—The $Li^7$ nuclear magnetic resonance in a LiCl water solution has been examined under high resolution for possible diurnal varaitions in linewidth. As previously discussed,[1,2] if a time varying anisotropy exists in inertial mass determined by Mach's principle, the maximum variation of the unresolved $Li^7$ resonance width would be $\Delta\nu=4\Delta m\hat{T}/5mh$. In New Haven, at 41° lat, on the dates of the 12-hr runs, the angle between a line to the Galactic Center and the direction of the magnetic field used swept from 20° through 100°. The observed linewidth of $1.2\pm0.2$ cps changed by $\leqslant 0.2$ cps. Using 10 Mev as the average kinetic energy $\hat{T}$ of the $Li^7$ nucleon, we obtain for the fractional mass anisotropy of the type discussed by Cocconi and Salpeter $\Delta m/m\leqslant 1\times10^{-23}$.

* This research was supported in part by the National Aeronautics and Space Administration.
[1] G. Cocconi and E. E. Salpeter, Phys. Rev. Letters 4, 176 (1960).
[2] V. W. Hughes, H. G. Robinson, and V. Beltran-Lopez, Phys. Rev. Letters 4, 504 (1960).

**F10. Fine Structure of Molecular Hydrogen in the Metastable $c^3\pi_u$ State.** WILLIAM LICHTEN, *University of Chicago*.—By means of the molecular beam, magnetic resonance method, observations of radio-frequency transitions in the metastable $c^3\pi_u$ state of para-$H_2$ have been made at microwave frequencies. Two of these have been identified as transitions between the fine structure components of a $N=2$ level. The measured intervals are

$$f(J=2\leftrightarrow J=3)=5898.105\pm0.012 \text{ Mc/sec.}$$
$$f(J=2\leftrightarrow J=1)=4928.003\pm0.010 \text{ Mc/sec.}$$

**F11. Measurement of the $2^3P$ Fine Structure of $He^4$ by Crossover Spectroscopy.*** J. LIFSITZ AND R. H. SANDS, *University of Michigan*.—Using the method of interference spectroscopy reported by Colegrove *et al.*,[1] the helium fine structure separation, $2P_0{}^3$-$2P_1{}^3$, has been measured to an accuracy of 6 parts in $10^8$. The method consists of illuminating with unpolarized 1-$\mu$ radiation a helium rf discharge situated in a magnetic field ($z$ axis) of 8282 gauss. The change in the forward scattered light ($x$ axis) caused by interference in the resonance fluorescence from the ($J=2$, $m=2$) and the ($J=0$, $m=0$) Zeeman levels of the $^3P$-states at crossover, is monitored. The value of the determined crossover field is inserted in the solutions of the secular equations[2] and the separation of the $2^3P_0$–$2^3P_1$ levels is computed to be $29\,619.1\pm1.9$ Mc/sec. This is to be compared with $29\,640\pm300$ Mc/sec previously found by optical methods.[1,3] Efforts are being made to increase precision and determine pressure effects, if any. Current data will be presented.

* Fully supported by the U. S. Atomic Energy Commission.
[1] F. D. Colegrove, P. A. Franken, R. R. Lewis, and R. H. Sands, Phys. Rev. Letters 3, 420 (1959); P. A. Franken, Phys. Rev. 121, 508 (1961).
[2] W. E. Lamb, Jr., Phys. Rev. 105, 559 (1957).
[3] Brochard *et al.*, J. phys. radium 13, 433 (1952).

**F12. Pure Rotational Raman Spectrum of Cyclopentane.*** KURT TANNER AND ALFONS WEBER, *Fordham University*.—The pure rotational Raman spectrum of cyclopentane vapor at 50°C was photographed with a plane grating spectrograph capable of high dispersion (ca 5 $cm^{-1}$/mm). The spectrum is quite weak and resembles that of a symmetric top rotator with a line spacing in the $S$ branch of about 0.864 $cm^{-1}$. Transitions with $J$ up to 63 were observed in the $S$ branch; the $R$ branch was mostly obscured by grating ghosts and did not yield any data. The analysis of the spectrum is based upon the symmetric rotor theory and yields the rotational constants $B_0=(0.21612\pm0.00007)$ $cm^{-1}$ and $D_0=(2.5\pm1)\times10^{-6}$ $cm^{-1}$. The cyclopentane molecule is not, however, a strict symmetric top as is conclusively shown by a careful analysis of the thermodynamic functions[1] and the vibrational spectrum.[2] The data obtained in this study do not admit any choice between the puckered ring model of Pitzer and Donath and the asymmetrical structure of Miller and Inskeep.

* Supported by the National Science Foundation.
[1] K. S. Pitzer and W. E. Donath, J. Am. Chem. Soc. 81, 3213 (1959).
[2] F. A. Miller and R. G. Inskeep, J. Chem. Phys. 18, 1519 (1950).

**F13. Two Mechanisms for Origin of Distribution of Shear Relaxation Times in Liquids.** D. O. MILES AND A. S. HAMAMOTO, *Lockheed Missiles and Space Company, Palo Alto, California*.—Two mechanisms are postulated as contributing to the distribution of shear relaxation times in liquids: (1) the absence of long-range order with resulting variation in activation energies, as set forth by Herzfeld and Litovitz,[1] and (2) the existence of close-packed short-lived pseudonuclie structures, as predicted by Bernal.[2] Neither theory is in quantitative form. Nevertheless, two experiments are described which, when qualitatively analyzed, give evidence that both mechanisms may contribute to the distribution of shear relaxation times in liquids. As a consequence, the existence of Bernal's pseudonuclei appears plausible.

[1] K. Herzfeld and T. A. Litovitz, *Absorption and Dispersion of Ultrasonic Waves* (Academic Press Inc., New York, 1959), 1st ed., pp. 454, 455.
[2] J. D. Bernal, Nature 185, 68 (1960).

**F14. Molecular Frictional Coefficient in Liquids.*** FRANK C. COLLINS AND EDWARD V. THOMPSON, *Polytechnic Institute of Brooklyn*.—A new expression for the frictional coefficient in liquids composed of spherically symmetric molecules is obtained by trajectory-density method in the near-equilibrium system. The method is an extension of that of Collins and Raffel[1] for calculating the frictional coefficient in a dense system of rigid

spheres and makes use of the same integration limits for the velocities of molecules moving together. The trajectory density at each point is taken as proportional to the equilibrium molecular density. The trajectories of those molecules moving apart are treated as reflections of the inwardly disposed trajectories by invoking microscopic reversibility. The resulting expression is weakly velocity dependent. Its low-velocity limiting form is $\zeta = 2(2\pi m/kT)K$, where $K$ is a scalar average over the first derivative of the intermolecular potential. It contrasts with earlier expressions for the frictional coefficient in which the square of the frictional coefficient is proportional to an average over the second space gradient of the potential. Both results are in approximate agreement with experiment in the case of liquid argon.

* This research was supported by the U. S. Air Force.
[1] F. C. Collins and H. Raffer, J. Chem. Phys. **23**, 1454 (1955).

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FRIDAY AFTERNOON AT 2:00 p.m.

Mandel Hall

(J. R. SCHRIEFFER presiding)

## *Superconductors*

### *Invited Papers*

**G1. Quantized Flux in Superconducting Cylinders.** W. M. FAIRBANK, *Stanford University.* (40 min.)

**G2. Some Theoretical Considerations on Superconductive Flux Trapping.** F. BLOCH, *Stanford University.* (40 min.)

**G3. Prospects for the Use of Superconductors in Particle Accelerators.** K. SYMON, *University of Wisconsin.* (30 min.)

### *Contributed Papers*

**G4. Characteristics of Some High Field Superconductors.*** R. R. HAKE, T. G. BERLINCOURT, AND D. H. LESLIE, *Atomics International.*—A "peak effect" has been observed in the critical current density vs magnetic field curve of cold-work Nb-15 atomic percent Sc and W-26 atomic percent Re, similar to that previously seen in Nb-12 atomic percent Zr.[1] A dependence of the critical current density on the orientation of the transverse magnetic field with respect to the rolled surface of the specimen[1] has been observed in nearly all the many cold-rolled binary transition metal alloys which have been examined. The absence of the effect in cold-rolled Ti-Mo alloys containing between 6 and 10 atomic percent Mo is probably associated with formation of omega phase during plastic deformation, as will be discussed. Approximately 2200 ft of Nb-25 atomic percent Zr[1] wire[2] have been utilized to form a superconducting solenoid with an i.d. of 0.5 cm, a length of 5 cm, a winding thickness of 2.1 cm, and a peak field of 45 kgauss.

* Supported in part by the U. S. Atomic Energy Commission.
[1] T. G. Berlincourt, R. R. Hake, and D. H. Leslie, Phys. Rev. Letters **6**, 671 (1961).
[2] Fabricated by the Wah Chang Corporation of Albany, Oregon.

**G5. Far Infrared Absorption in Lead-Thallium Superconducting Alloys.*** J. D. LESLIE AND D. M. GINSBERG, *Department of Physics, University of Illinois.*—We have measured the absorption of far infrared radiation in the surface of bulk superconducting alloys composed of various concentrations of thallium in lead. The results indicate that the gap edge is quite distinct, in contrast to previous results on other alloys.[1] The sharpness of the gap edge is thought to be characteristic of alloys which are homogeneous and have no trapped magnetic flux. The subsidiary absorption maximum below the gap edge, which has been seen previously in pure lead, is also present in the alloys. This lends support to other evidence[2] that it is not due to crystalline anisotropy. A comparison will be made between the observed and the predicted[3-5] effect of alloying on the gap width.

* Supported in part by the A. P. Sloan Foundation and the National Science Foundation.
[1] P. L. Richards and M. Tinkham, Phys. Rev. **119**, 575 (1960).
[2] D. M. Ginsberg and M. Tinkham, Phys. Rev. **118**, 990 (1960).
[3] H. Suhl and B. Matthias, Phys. Rev. **114**, 977 (1959).
[4] D. J. Kenworthy and D. ter Haar, Phys. Rev. **123**, 1181 (1961).
[5] K. Nakamura, Progr. Theoret. Phys. (Kyoto) **21**, 435 (1959).

**G6. A Spectroscopic Observation of the Anisotropy of the Energy Gap in Superconducting Tin.** P. L. RICHARDS, *Bell Telephone Laboratories, Inc.*—We have used the far-infrared techniques developed by Richards and Tinkham[1] to investigate the anisotropy of the energy gap in superconducting tin. For a given crystal orientation, because of the anomalous skin effect, the electromagnetic field interacts most strongly with a band of electrons around the Fermi Surface. Anisotropy of the gap for electrons in this band shows up as a broadening of the optical absorption edge. We also observe a variation of the position of the absorption edge with crystal orientation which is qualitatively similar to the results of ultrasonic attenuation measurements. In impure specimens the absorption edge is narrowed indicating a decrease in anisotropy. We thus verify the prediction of Anderson's theory of dirty superconductors.[2] The gap in impure tin is somewhat less than 3.5 kTc. All of the absorption edges measured have structure in the form of a peak at ~4.2 kTc.

[1] P. L. Richards and M. Tinkham, Phys. Rev. **119**, 575 (1960).
[2] P. W. Andersen, J. Phys. Chem. Solids **11**, 26 (1959).

FRIDAY AFTERNOON AT 2:00 p.m.

Breasted Hall, The Oriental Institute

(J. A. MARCUS, presiding)

## *Semiconductors I*

### *Invited Paper*

**H1. Effect of Strain on Donor Wave Functions in Germanium.** H. FRITZSCHE, *University of Chicago.* (30 min.)

### *Contributed Papers*

**H2. Strain Dependence of the Acceptor Ground State and Transport Properties of *p*-Type Germanium.** JOHN J. HALL, *IBM Watson Laboratory.*—The conductivity, Hall mobility, and activation energy have been measured at low temperatures for pure *p*-type germanium subject to large uniaxial compressions in the ⟨111⟩ direction; the data will be analyzed in the light of Price's recent theory of the strain dependence of the acceptor ground state energy.[1] The ratio of the Hall mobilities at saturation strain parallel and perpendicular to the strain axis has been determined by four-terminal methods to be $(\mu_H/\mu_{H\perp})_{sat} \cong 3$, demonstrating unambiguously that the energy ellipsoid for carriers in the thermal band is prolate.[2] This result, coupled with an extension of Price's theory to the ⟨111⟩ case, permits the calculation of a provisional value of the rhombohedral deformation potential constant, $|d| = 11$ ev, in the notation of Pikus and Bir.[3]

[1] P. J. Price, Phys. Rev. (to be published).
[2] Cf. S. H. Koenig and J. J. Hall, Phys. Rev. Letters 5, 55 (1960).
[3] G. E. Pikus and G. L. Bir, Soviet Phys.-Solid State 1, 1502 (1960).

**H3. Valence Band Parameters of Stressed Ge.*** T. R. LOREE,† M. H. HALLORAN, AND R. N. DEXTER, *The University of Wisconsin.*—Measurements of valence band parameters have been made in Ge and Si by means of cyclotron resonance in crystals subjected to uniaxial stress. This investigation overlaps earlier work on silicon.[1] Data were taken in waveguide at 23.8 and 9 kMc/sec and at 1.3° and 4.2°K under variable compressive stresses up to about 7000 kg/cm² applied either in the [100] or [111] direction. Preliminary numbers in units of $\hbar^2/2m$ for holes in germanium with pressure of 2500 kg/cm² along [100] are $A = -11.5$, $|B| = 9.0$ and with similar compression along the [111], $A = -11.1$, $|N| = 30$. Small pressure effects were found for these parameters but electron masses did not shift from their zero-stress values. We have not accounted for the disagreement with values of $A$ obtained in zero-stress experiments. It should be noted that for compressions along the [100] and [111] directions in both Si and Ge the highest energy valence band ellipsoids of revolution were oblate, that is, $m_\perp > m_\parallel$.

* Supported in part by the Wright Air Development Center.
† National Science Foundation Cooperative Fellow.
[1] J. C. Hensel and G. Feher, Phys. Rev. Letters 5, 307 (1960).

**H4. Valley-Orbit Splitting in Sb-Doped Ge.** R. E. PONTINEN AND T. M. SANDERS, JR., *University of Minnesota.*—We have measured the singlet-triplet splitting in the 1*s* state of Sb donors in Ge by studying the influence of uniaxial stress on the Sb donor electron spin resonance.[1] This method has previously been applied to P and As donors.[2] The samples are located in an *x*-band resonant cavity at liquid helium temperature and are subjected to [110] compression up to $4.5 \times 10^8$ dyne cm$^{-2}$. The *g* factor has been measured as a function of stress and of the orientation of $\mathbf{H}_0$ in the (110) plane. The most detailed measurements have been performed at 1.3°K on samples of room temperature resistivity varying from 0.09 to 3.8 ohm-cm. we obtain from these measurements the value $\Delta_e/E_2 = (0.519 \pm 0.010) \times 10^{-3}$. This gives for the singlet-triplet splitting the value $4\Delta_e = 4.04 \times 10^{-4}$ ev which may be compared with the value $4\Delta_e = (5.7 \pm 0.3) \times 10^{-4}$ ev obtained from piezoresistance measurements.[3] The same method applied to *P*-doped Ge yields a singlet-triplet splitting in agreement with previous measurements.

[1] G. Feher, D. K. Wilson, and E. O. Gere, Phys. Rev. Letters 3, 25 (1959).
[2] D. K. Wilson and G. Feher, Bull. Am. Phys. Soc. 5, 60 (1960).
[3] H. Fritsche, Phys. Rev. 120, 1120 (1960).
[4] R. E. Pontinen and T. M. Sanders, Jr., Phys. Rev. Letters 5, 311 (1960).

**H5. Magnetoresistance and Piezoresistance in *P*-Type Gallium Antimonide.** O. N. TUFTE AND E. L. STELZER, *Honeywell Research Center.*—Magnetoresistance and piezoresistance measurements have been made on *p*-type gallium antimonide crystals having an impurity concentration of approximately $10^{17}$ cm$^{-3}$. The phenomenological magnetoresistance coefficients *b*, *c*, and *d* have been evaluated at 77° and 300°K. The coefficient *b* has values of $11.4 \times 10^{-10}$ and $6.8 \times 10^{-11}$ gauss$^{-2}$ at 77° and 300°K, respectively. The coefficient *d* is negative and the ratios $|d/b|$ and $(b+c)/b$ are both 0.21 at 300°K and reduce to 0.12 at 77°K. The Hall mobility in these samples is 3380 and 830 cm²/volt-sec at 77° and 300°K, respectively. Piezoresistance measurements have been made from 77° to 350°K. At 300°K, the measured values of the piezoresistance coefficients $\pi_{11}$, $\pi_{12}$, and $\pi_{44}$ are $-3.5 \times 10^{-12}$, $+1 \times 10^{-12}$, and $+60 \times 10^{-12}$ cm²/dyne, respectively. Both the magnetoresistance and piezoresistance effects in gallium antimonide are qualitatively very similar to the effects found in *p*-type germanium indicating that the valence band structure of gallium antimonide is similar to germanium.

**H6. Theory of Indirect Absorption.** R. L. HARTMAN, *IBM and Columbia University.*—Published versions of the Bardeen-Blatt-Hall process neglect the variation of the energy denominator with the energy of the intermediate states. A more exact analysis shows that, in the expression for the absorption constant from each hole band, $X^2$ is replaced by

$$\frac{8}{C^2}\left\{\frac{2+(C-2)X}{[2(1+(C-2)X+(1-C)X^2)^{\frac{1}{2}}]}\right\},$$

where $X = (\nu - \nu_{indirect})/(\nu_{direct} - \nu_{indirect})$ and $C-1$ is (hole mass)/(zone-center electron mass). The resulting theoretical absorption curve has been calculated for germanium. The corresponding result for the more general case of degenerate material (when the process will be induced by impurity atoms rather than phonons) has also be obtained, and absorption curves calculated for various Fermi energies.

**H7. Absorption Coefficient of Zn-As-Doped Germanium at 55°K.** D. C. CRONEMEYER AND W. N. FETZNER, *Bendix Research Laboratories.*—Optical absorption studies covering the 0.05 to 0.8 ev photon energy range at 55°K have been made

upon compensated zinc plus arsenic-doped germanium samples exhibiting the 0.09 ev second hole ionization energy. The absorption coefficient information is derived from three thicknesses of each sample, in order to avoid difficulties from surface layers. Hall effect and distribution coefficient studies have been made in order to estimate the zinc and arsenic concentrations. In order to obtain the bound-hole absorption coefficient spectrum, the lattice absorption coefficient spectrum has also been obtained at 55°K for germanium samples which are intrinsic at 300°K (these lattice absorption coefficient spectra are compared with other published data). Utilizing these pieces of data, the bound hole absorption coefficient spectrum can be obtained and converted into an absorption cross-section spectrum. Such an absorption cross-section spectrum shows a triangular shape with a precipitous drop below 0.0755 ev, preceded by a peak in some samples, but not in others. This 0.0755 ev absorption peak probably corresponds to one already reported[1] to lie at 0.0749 ev at 4°K.

[1] P. Fisher and H. Y. Fan, Phys. Rev. Letters 5, 196 (1960).

**H8. Free-Carrier Magneto-Kerr Effect in Semiconductors.** M. E. BRODWIN, J. K. FURDYNA, AND R. J. VERNON, *Northwestern University.*—Upon reflection from a semiconductor placed in a magnetic field, an incident linearly polarized electromagnetic wave becomes elliptically polarized, with the major axis of the ellipse rotated relative to the initial plane of polarization. A plane wave analysis of this phenomenon is carried out on the basis of the free-carrier semiconductor model for the case where the directions of incidence and of the applied dc magnetic field are normal to the surface. General expressions relating the magneto-Kerr ellipticity and rotation to the conductivity, mobility, relaxation time and dielectric constant are developed. For certain ranges of the magnetic field, frequency, and dielectric loss these rather complicated expressions are reduced to more revealing forms, which can be readily applied to experimental measurement. It appears that the magneto-Kerr effect should be particularly useful in experimental investigation of transport parameters in high-conductivity semiconductors where experiments involving transmission or significant penetration are impractical. We have observed and made preliminary measurements of the magneto-Kerr effect on a slab of 2 ohm-cm $n$-type germanium at 9 kmc in fields up to 5 kgauss. The measurements were carried out in the $TE_{11}$ mode of a circular waveguide (where the plane wave analysis applies as a good approximation), using a turnstile junction in a double microwave bridge arrangement. The results were in complete qualitative agreement with the theory. A quantitative calculation, based on published values of transport parameters characteristic of 2 ohm-cm $n$-type germanium, agreed within 30% with our observations. Further theoretical and experimental investigation of this phenomenon is now in progress.

**H9. Oscillatory Microwave Magnetoconductivity in Gray Tin.*** R. N. DEXTER AND D. H. HENSLER, *The University of Wisconsin,* AND A. W. EWALD, *Northwestern University.*—Oscillations have been observed in the microwave absorption as a function of magnetic field in gray tin single crystals at temperatures from 1° to 50°K. Cavity techniques were utilized at frequencies of 23.8 and 9.2 kMc/sec. Absorption and absorption derivatives were studied in crystals which replaced part of the end-wall of the cavity. Both natural and rough-cut faces gave the oscillations with the magnetic field either perpendicular or parallel to the crystal surface. It was apparent that the oscillations were not cyclotron resonance effects since peaks were found at the same fields at the two microwave frequencies although more oscillations and higher resolution were noted at the higher frequency. When the temperature increased above 1.3°K the peaks shifted to ever-increasing fields due to the increase in the Fermi energy. More oscillations became apparent at temperatures well above 4.2°K. At 23.8 kMc/sec one peak could be followed from 680 gauss at 1.3°K to 9000 gauss near 50°K. Up to 5 harmonics were noted in some instances. (100) and (111) surfaces have been studied but band-structure interpretation is not complete. Peaks were also observed in the absorption of additional carriers excited by chopped light.

* The work at Wisconsin was supported by the Wright Air Development Center and the work at Northwestern was supported jointly by the Office of Naval Research of the Navy Department and by the Advanced Research Projects Agency of the Department of Defense.

**H10. A Method for Determination of Conduction Mechanisms.** M. POLLAK, *Westinghouse Research Laboratories.*—The frequency dependence of the conductivity can be used to distinguish between hopping and band type conduction mechanisms. It is shown that the real part of the conductivity should be an increasing function of frequency for the case of hopping and a decreasing function of frequency for the case of conduction in a band. This is because of the fact that when an electric field is applied, conduction is due to a change in the distribution of carriers in momentum space for the case of band conduction, while in the case of hopping, it is due to a change in distribution in real space. Misleading results may be obtained when inhomogeneities are present in materials with band conduction, because a change in the distribution may now occur also in the real space. Using a slight generalization of Herring's theory,[1] it can be shown, however, that the frequency dependence due to the inhomogeneities is rather small for materials with a reasonable degree of inhomogeneity.

[1] Conyers Herring, J. Appl. Phys. 31, 1939 (1960).

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## FRIDAY AFTERNOON AT 2:00 p.m.

## Judd 126

## (P. AXEL, presiding)

## *Nuclear Moments and Beta-Gamma Spectroscopy I*

**I1. Nuclear Spin of $Cd^{107}$.*** M. MCDERMOTT AND R. NOVICK, *Columbia Radiation Laboratory.*—The ground-state nuclear spin of $Cd^{107}$ has been determined to be $1=\frac{1}{2}$ by an optical double resonance technique. The determination thus far rests on the observation of a single Zeeman resonance in the $5\,^3P_1$ state, as well as on the lack of resonances which would be expected for other spins. Difficulties arising from the presence of a large stable cadmium contamination have prevented a second expected resonance from being seen. The identity of the nucleus involved is established by noting the decay of the resonance signal with time. This decay is well fitted by an exponential with a decay constant of 6.7 hr corresponding to the known half-life of $Cd^{107}$.

* Work supported in part by the U. S. Air Force monitored by the Air Force Office of Scientific Research.

**I2. Magnetic and Hyperfine Splitting of $Cs^{134m}$ by Atomic Beams.*** V. W. COHEN, T. I. MORAN, AND S. PENSELIN, *Brookhaven National Laboratory.*—The two hyperfine transitions in the 3.1-hr metastable state of $Cs^{134}$

$$\left(\frac{17}{2},\frac{-15}{2}\right)\leftrightarrow\left(\frac{15}{2},\frac{-13}{2}\right) \quad \text{and} \quad \left(\frac{17}{2},\frac{-13}{2}\right)\leftrightarrow\left(\frac{15}{2},\frac{-15}{2}\right)$$

form a doublet with a separation exactly equal to $2g_I\mu_0H$. Ramsey patterns of these transitions have been observed using an atomic beam magnetic resonance apparatus of the "flop-in" type.[1] The approximate frequency of the doublet was 2065 Mc/sec with a splitting of 228 702±25 cps. The magnetic field was calibrated by using the $\Delta F=0$ transition in stable $Cs^{133}$. Assuming values of 2.57887 nm for $\mu_{133}$ and 2.00258 for $g_I$, we calculate the value $\mu_{134m}=1.0964\pm0.0002$ nm. The hyperfine splitting $\Delta\nu$ of $Cs^{134}$ was obtained by observing the transitions

$$\left(\frac{17}{2},\frac{1}{2}\right)\leftrightarrow\left(\frac{15}{2},-\frac{1}{2}\right) \quad \text{and} \quad \left(\frac{17}{2},-\frac{1}{2}\right)\leftrightarrow\left(\frac{15}{2},+\frac{1}{2}\right)$$

in a very low field where they are nearly field independent. The result is $\Delta\nu=3\,684\,578\,640\pm175$ cps referred to $Cs^{133}$ hyperfine frequency of 9 192 631 770 cps. With these results the hyperfine structure anomaly between $Cs^{133}$ and $Cs^{134m}$ is $-0.0139\pm0.0002$. The values of $g_I$ and ${}_{133}\Delta_{134m}$ in reference 1 were in error probably because of line distortion due to inhomogeneities in the $C$ field.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] V. W. Cohen and J. Schwartz, Bull. Am. Phys. Soc. 5, 273 (1960).

**I3. L/K-Capture Ratio in $Mn^{54}$, $Fe^{55}$, $Co^{57}$, and $Co^{58}$ Decays.*** R. W. FINK† AND R. B. MOLER, *University of Arkansas.*—Multiwire proportional counter measurements of the $L$ and $K$ radiations from orbital electron capture in gaseous sources of 290 day $Mn^{54}$, 2.6 year $Fe^{55}$, 270 day $Co^{57}$, and 72 day $Co^{58}$ have been made. The presence of gammas and positions in $Mn^{54}$, $Co^{57}$, and $Co^{58}$ decays is shown not to interfere with an accurate measurement of the $L/K$-capture ratio. Experimental values of this ratio are $0.098\pm0.006$ for $Mn^{54}$, $0.106\pm0.005$ for $Fe^{55}$, and $0.108\pm0.004$ for $Co^{58}$, the work on $Co^{57}$ being in progress. The result for $Fe^{55}$ is in excellent agreement with the earlier value measured by Scobie, Moler, and Fink,[1] although the present value has been corrected for counter escape somewhat more exactly. The experimental values lie slightly above the theoretical results of Brysk and Rose[2] by some 9% for $Mn^{54}$, 9.3% for $Fe^{55}$, and 17% for $Co^{58}$. These discrepancies are reduced somewhat by the Pauli correlation corrections pointed out by Odiot and Daudel,[3] but even so they remain largely unexplained. The $K$-shell fluorescence yields of chromium and manganese have been measured by a multiwire counter technique to be $0.20\pm0.03$ and $0.33\pm0.03$, respectively.

* Supported in part by the National Science Foundation.
† Present address: Department of Physics, Marquette University, Milwaukee 3, Wisconsin.
[1] J. Scobie, R. B. Moler, and R. W. Fink, Phys. Rev. 116, 657 (1959).
[2] H. Brysk and M. E. Rose, AEC Rept. ORNL-1830 (1955); Revs. Modern Phys. 30, 1169 (1958).
[3] S. Odiot and R. Daudel, J. phys. radium 17, 60 (1956).

**I4. Decay of 18-Min $Br^{80}$.*** P. N. TREHAN† AND D. M. VAN PATTER, *Bartol Research Foundation.*—The decay of $Br^{80}$ has been investigated by means of scintillation spectrometry. The 18-min $Br^{80}$ was produced by proton bombardment of 99.4% enriched $Se^{80}$ targets with $E_p=4.0$ Mev. Gamma rays of energy 0.62, 0.67, 1.26, and 1.33 Mev (±1%) were observed in singles spectra, and $\gamma$ rays of energy 0.64 and 0.71 Mev appeared in coincidence with the 0.62-Mev $\gamma$ ray. The 0.62-Mev $\gamma$ ray arises from the known level at 0.62 (2+) Mev in $Kr^{80}$. The 0.64- and 1.26-Mev $\gamma$ rays are assigned to a new level at 1.26 Mev in $Kr^{80}$, and the 0.71- and 1.33-Mev $\gamma$ rays are assigned to a second new level at 1.33 Mev in $Kr^{80}$. The level at 1.26 Mev is considered to be the second 2+ level, both on the basis of systematics[1] and the log ft value of the beta transition to this level. The 0.67-Mev $\gamma$ ray is assigned to the first 2+ level in $Se^{80}$. The ratio of 0.62 $\gamma/\beta+$ has been measured as $2.6\pm0.1$, which is used for the evaluation of the log ft values for the transitions to various levels in $Se^{80}$ and $Kr^{80}$.

* Supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
† On leave from the Panjab University, Chandigarh, Panjab, India.
[1] D. M. Van Patter, Bull. Am. Phys. Soc. 3, 212 (1958).

**I5. Gamma-Gamma Directional Correlations in $Rh^{105}$.*** ATAM P. ARYA, *Pennsylvania State University.*—The directional correlation measurements have been made on the 320–475 kev and 485–475 kev gamma-gamma cascades in $Rh^{105}$ following the decay of 4.5-hr half-life $Ru^{105}$ with a coincidence scintillation spectrometer using NaI detectors. The observed correlation functions are

$$W(\theta)=1+(0.035\pm0.005)P_2(\cos\theta)-(0.017\pm0.004)P_4(\cos\theta)$$

and

$$W(\theta)=1+(0.171\pm0.016)P_2(\cos\theta)+(0.137\pm0.004)P_4(\cos\theta),$$

respectively, for the two cascades. These gamma-gamma directional correlations have been found to be consistent with the spin assignment of $\frac{7}{2}$, $\frac{7}{2}$, $\frac{5}{2}$, and $\frac{7}{2}$ to the levels at the ground state, 475, 795, and 960 kev in $Rh^{105}$. The probable assignment of multipolarities for different gamma rays is as follows: The 475-kev gamma ray has a mixture of (30–55)% dipole and (45–70)% quadrupole. The 485-kev gamma ray has a mixture of (0–20)% dipole and (80–100)% quadrupole. The 320-kev gamma ray has a mixture of (95–97.5)% dipole and (2.5–5)% quadrupole.

* This work was supported in part by the U. S. Atomic Energy Commission.

**I6. Characterization of $Ru^{107}$, $Ru^{103}$, $Rh^{107}$, and $Rh^{103}$.*** WILLIAM R. PIERSON, HENRY C. GRIFFIN, AND CHARLES D. CORYELL, *MIT.*—Detailed $\beta$, $\gamma$, and coincidence scintillation-spectrometry has been applied to the radiations from short-lived neutron-rich ruthenium isotopes and their descendants. By taking ruthenium from fission, by $U^{235}(n,F)$ and $Th^{232}(d,F)$, distinction was made between 4.2-min $Ru^{107}$ and 4.6-min $Ru^{103}$. Mass assignment of 21.7-min $Rh^{107}$ comes from production in the reactions $Ru^{104}(\alpha,p)$ and $Pb^{208}(n,pn)$; the mass assignment of (16.5±0.5)-sec $Rh^{103}$ comes from its $\gamma$ spectrum. Decay properties of $Ru^{107}$ are: $Q^\beta=4.6\pm0.4$ Mev; a $\gamma$ ray (energy in kev) of 195 (14%) partly in coincidence with 370, 480(?), and 860; and low intensity $\gamma$ rays of higher energy. $Rh^{107}$ has $\gamma$ rays of 307 (75%), partly in coincidence with 365; with the pair 285 plus 390 in parallel; and also 115, 460, 570, and 680 (all low intensity). $Ru^{103}$ has $Q^\beta=1.32\pm0.1$ Mev and a $\gamma$ ray of 165 (28%). $Rh^{103}$ has $Q^\beta=4.0\pm0.6$ Mev; and $\gamma$ rays of 430 (43%), partly in coincidence with 510 (10%) and 620 (22%), 1520 (5%) and several more of high energy and low intensity. $Ru^{107}$ or $Ru^{103}$ has an x ray (<10%).

* Work supported in part by the U. S. Atomic Energy Commission.

**17. Decay of $Ag^{105m}$.*** E. G. FUNK, JR., G. C. MARTIN, R. C. PILGER, JR., AND J. W. MIHELICH, *University of Notre Dame.*—The decay of $Ag^{105m}$ (>5 yr) has been studied using one source consisting of about 50% $Ag^{105m}$ and 50% $Ag^{110m}$ and another of almost pure $Ag^{110m}$. Gamma- and beta-ray scintillation spectra and coincidence measurements indicate that $Ag^{105m}$ decays predominantly by electron capture to a state at about 1770 kev in $Pd^{105}$ and by a low-energy isomeric transition followed by an 80-kev gamma ray to $Ag^{105}$, confirming the decay scheme proposed by Wahlgren and Meinke.[1] Three gamma-ray transitions of 720, 620, and 434 kev, all of equal

intensity, are in cascade in $Pd^{108}$. The 434-kev transition, which has been observed by Coulomb excitation and in the decay of $Ag^{108}$ (2.3 min), lies lowest. Gamma-gamma directional correlation measurements have been carried out on all gamma-ray pairs in the cascade. The correlations are all identical within experimental errors and are in good agreement with spins of 2, 4, and 6 for the 434-, 1054-, or 1154-, and 1774-kev levels, with all transitions being pure quadrupole. They do not, however, resolve the ambiguity concerning the order of the 720- and 720-kev transitions.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] M. Wahlgren and W. W. Meinke, Phys. Rev. 118, 181 (1960).

**I8. Electron Capture Decay of $Gd^{149}$.*** H. J. PRASK, J. J. REIDY, E. G. FUNK, JR., AND J. W. MIHELICH, *University of Notre Dame.*—The electron capture decay of $Gd^{149}$ has been studied with an intermediate image $\beta$-ray spectrometer, scintillation spectrometers, and prompt and delayed coincidence techniques. It was found that both the 650- and 937-kev transitions reported previously by Shirley *et al.*[1] were composite. We confirm the assignment of the 750- and 790-kev transitions by Shirley *et al.*[1] to this activity. Multipolarities and log ft values were obtained from relative gamma-ray and electron intensities. Energy levels and spins and parities are proposed in $Eu^{149}$ at 0 kev (5/2+), 150 kev (7/2+), 423 kev, 497 kev (11/2−, $T_{\frac{1}{2}}=2.42\ \mu s$), 750 kev (5/2, 7/2−), 796 kev (9/2−), 940 kev (5/2, 7/2, 9/2−), 958 kev, and ~1085 kev. The half-lives of the other levels were found to be less than 2 m$\mu$sec. A $\gamma$-$\gamma$ directional correlation performed on the (347–150 kev) cascade suggests the possibility of mixed multipole order for either or both of the transitions.

* Supported in part by the U. S. Atomic Energy Commission.
[1] V. S. Shirley, W. G. Smith, and J. O. Rasmussen, Nuclear Phys. 4, 395 (1957).

**I9. Decay of the Isomeric States of $Eu^{150}$.*** MARK GUTTMANN, H. J. PRASK, J. J. REIDY, E. G. FUNK, JR., AND J. W. MIHELICH, *University of Notre Dame.*—Transitions of 0.334, 0.440, 0.590, 0.740, and 1.07 Mev were observed in the electron capture decay of $Eu^{150}$ (5 yr). On the basis of coincidence studies a decay scheme is proposed with levels in $Sm^{150}$ at 0.334, 0.774, 1.07, 1.36, 1.81, and 1.84 Mev. A gamma-gamma correlation measurement on the 0.440-0.334 cascade is consistent with assignments of 2+ and 4+ for the 0.334- and 0.774-Mev levels. The 14-hr $Eu^{150}$ decays by $\beta^-$ (87%), $\beta^+$ (0.3%), and electron capture (12.7%). The beta spectrum consists of a single component whose end point is 1.02 Mev, and the positron spectrum exhibits an end point of 1.25 Mev. A low-energy positron branch may be present. In additon to the gamma rays observed by Harmatz *et al.*,[1] a transition of 1.97 Mev was observed. The results of coincidence and gamma-gamma correlation experiments establish levels at 0.334 Mev (2+), 0.740 Mev (0+), 1.26 Mev (0+), and 1.97 Mev (1−?).

* Work supported in part by U. S. Atomic Energy Commission.
[1] B. Harmatz, T. H. Handley, and J. W. Mihelich, Phys. Rev. 123, 1758 (1961).

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FRIDAY AFTERNOON AT 2:00 p.m.

Eckhart 133

(A. B. SMITH, presiding)

## *Fast Neutrons and Other Nuclear Physics*

**J1. Klystron-Type Beam Buncher.** C. H. POPPE, R. R. BORCHERS, AND H. W. LEFEVRE, *University of Wisconsin.**—A klystron-type beam buncher[1] for a fast neutron time-of-flight spectrometer has been constructed for use with a tandem electrostatic accelerator. The buncher is located between the negative ion source and the accelerating tube. The beam, either negative hydrogen or negative deuterium ions, is bunched prior to acceleration and chopped after acceleration. The buncher impresses an rf velocity modulation on the negative ion beam so that when the positive particle beam arrives at the chopping plates its intensity is modulated. The energy modulation introduced in the beam is less than 6 kev. The buncher and chopping plates are driven at the same frequency, but the phase difference must be adjusted as the flight time between them varies with machine energy. The buncher produces a factor of eight increase in chopped beam. This increase is limited by the energy spread of the negative ions entering the buncher. The duration of the beam pulses after chopping is not impaired by the buncher, and remains less than 2 nsec.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] N. N. Flerov and E. A. Tamanov, Atomnaya Energ. 3, 44 (1957).

**J2. Breakup Neutrons from Protons on Tritium.*** C. H. HOLBROW, R. R. BORCHERS, AND C. H. POPPE, *University of Wisconsin.*—The breakup neutrons emitted at 0° from the reaction $T(p,np)D$ were investigated for proton bombarding energies of 12 and 13 Mev using the time-of-flight spectrometer mentioned in the preceding abstract. Tritium gas was contained between two 0.5-mil tantalum foils. The protons were stopped in $Ni^{68}$ deposited on gold. The neutrons were detected in a cylindrical liquid scintillator, 1 in. thick and 3 in. in diameter, which was viewed by an Amperex 58 AVP phototube. Pulse-shape discrimination was used to eliminate background counts from gamma rays, which occur in the portion of the time spectrum corresponding to breakup neutrons. Background neutrons, however, caused 85% of the counts in this region. The cross section for breakup neutrons with energy greater than 2 Mev was calculated with reference to the monoenergetic neutrons from $T(p,n)He^3$, which were observed simultaneously with the breakup neutrons. This cross section was found to have an upper limit of 3 mb/sr at 12 Mev and a value of $5\pm1$ mb/sr at 13 Mev.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

**J3. Neutrons from Proton Bombardment of Lithium.*** R. R. BORCHERS, C. H. POPPE, AND C. H. HOLBROW, *University of Wisconsin.*—The zero-degree yield of neutrons from the bombardment of 100-kev-thick metallic lithium targets by protons of energies from 3 to 10 Mev has been measured. The data were taken in 250-kev steps using the time-of-flight system mentioned in the preceding papers. Neutrons leaving $Be^7$ in the ground state and the first excited state were resolved. Angular distributions of these two groups were taken in 500-kev steps. Measurements at 9-, 10-, 11-, 12-, 13-Mev proton energy also gave the yield of neutrons leaving $Be^7$ in the second excited state at 4.53 Mev. No neutrons leaving $Be^7$ in higher excited states or from three-body reactions were observed. The neutron yield to the ground state of $Be^7$ is strongly forward-peaked.

The zero-degree yield of these neutrons decreases from about 60 mb/sr at 5 Mev to 4 mb/sr at 10 Mev. Neutrons leaving $Be^7$ in the first excited state are relatively more abundant at higher energies, reaching 30% of the total yield at 10 Mev.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

**J4. Neutron Polarizations in Scattering from $Li^6$, $Li^7$, and Mg.*** R. O. LANE, A. J. ELWYN, AND A. LANGSDORF, JR., *Argonne National Laboratory.*—The azimuthal asymmetry in the scattering of partially polarized neutrons from the $Li^7(p,n)Be^7$ reaction (at 51° emission angle relative to the incident proton direction) has been measured at energies from 0.2 to 2.0 Mev for $Li^6$ and $Li^7$, and from 0.2 to 0.7 Mev for Mg. Asymmetries were determined at five different angles of scatter simultaneously by measurement of counting rates both with and without the precession of the neutron spin through 180° by the transverse field of an electromagnet. A striking feature of the results is the nearly identical polarizations in $Li^6$ and $Li^7$ from 0.5 to 2.0 Mev, where both are approximately of the form $P(\theta)=A\sin 2\theta$. From the known neutron source polarization, it follows that $A$ is negative and is as large as $-0.4$ at the higher energies. The angular distribution of the polarization $P(\theta)$ and that of the unpolarized differential cross section $\sigma(\theta)$ for natural Mg are presented along with their values predicted from a fit to the total cross section of $Mg^{24}$. The large polarizations (up to 95%) observed in this energy range make Mg attractive as an analyzer in spite of the complications due to the isotopes $Mg^{25}$ and $Mg^{26}$ in the natural element.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**J5. Polarization of Neutrons from the $Li^7(p,n)Be^7$ Reaction.*** T. H. MAY, W. BENENSON, AND R. L. WALTER, *University of Wisconsin.*—The polarization of neutrons produced in the $Li^7(p,n)Be^7$ reaction was measured for proton energies from 4 to 10 Mev. Neutrons corresponding to transitions to the ground state and the first excited state of $Be^7$ were not distinguished and were measured with about equal efficiency. The angular distributions of polarization change considerably with proton energy. Maxima in the laboratory angular distributions at 4.0, 4.7, 5.9, and 6.9 Mev bombarding energies are $0.33\pm0.03$ at 40°, $0.28\pm0.02$ at 30°, $-0.18\pm0.03$ at 70°, and $-0.19\pm0.02$ at 20°, respectively. Above 6.9 Mev no polarizations of magnitude greater than 0.17 were observed for the laboratory angles studied (<110°). The present results agree reasonably well with earlier work at proton energies below 6 Mev.[1]

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] J. A. Balcker and K. W. Jones, Nuclear Phys. 17, 424 (1960).

**J6. Polarization of Neutrons from the $D(d,n)He^3$ Reaction.*** R. L. WALTER, P. S. DUBBELDAM, AND R. F. LANFERMAN, *University of Wisconsin.*—The polarization of neutrons from the $D(d,n)He^3$ reaction has been determined for seven deuteron energies from 1.9 to 11 Mev by measuring the asymmetry in scattering from helium. The helium was contained, under high pressure, in a thin-walled cell which was prepared in such a manner that scintillations produced by the helium recoils could be viewed with a phototube. Background counts were reduced by observing coincidences between the helium recoils and the scattered neutrons which were detected in plastic scintillators. A magnetic field produced in a solenoid was used to rotate the polarization vector of the neutrons. For a reaction angle of 45° c.m., the polarization was found to vary gradually from $-0.12\pm0.02$ at 1.9 Mev to $+0.30\pm0.05$ at 11 Mev, passing through zero at about 4.2 Mev. Polarizations were also obtained as a function of reaction angle at 1.9, 3.0, 3.7, 7.0, and 8.9 Mev.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

**J7. Polarization of Neutrons from the $T(p,n)He^3$ Reaction.*** W. BENENSON, P. S. DUBBLEDAM, T. H. MAY, AND R. L. WALTER, *University of Wisconsin.*—The polarization of neutrons produced in the $T(p,n)He^3$ reaction has been measured at seven proton energies from 2.9 to 12 Mev. The angular dependence of the polarization was determined at 2.9, 4.0, 5.0, 6.0, and 12.0 Mev. For center-of-mass-reaction angles near 45°, the measured polarization has a maximum of 0.26 for a 2.0-Mev incident proton, goes through zero near 5 Mev, and remains nearly constant at $-0.20$ from 8 to 12 Mev. Considerable variation in the shape of the angular distribution of polarization was observed for proton energies from 2.9 to 6 Mev. However, the shape of the 6-Mev distribution is similar to that at 12 Mev and is also similar to that observed by Artemov *et al.*[1] at 8 and 10 Mev.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] K. P. Artemov, N. A. Vlasov, and L. N. Samoilov, Soviet Phys.—JETP 10, 841 (1960).

**J8. Fast-Neutron-Capture Cross Section of $Ni^{64}$.*** H. A. GRENCH, W. L. IMHOF, AND F. J. VAUGHN, *Lockheed Missiles and Space Company Research Laboratories.*—The fast-neutron-capture cross section of $Ni^{64}$ has been measured between about 100 and 1400 kev by observing the gamma-ray activity of the 2.6-hr $Ni^{65}$ produced. The neutron flux was determined from the simultaneous activation of $Au^{198}$. Nickel enriched to 96.5% $Ni^{64}$ was irradiated with neutrons produced by the $Li^7(p,n)Be^7$ reaction, using a Van de Graaff generator. The cross section decreases from about 3 mb at 100 kev to about 2 mb at 450 kev and stays approximately constant to 1400 kev. The data will be compared with predictions of the statistical theory of nuclear reactions.

* Supported jointly by the Lockheed General Research Program and the U. S. Atomic Energy Commission.

**J9. Deuteron Compton Effect.*** R. S. JONES, H-J. GERBER, A. O. HANSON, AND A. WATTENBERG, *University of Illinois.*—Elastic scattering by deuterons of photons in the range of 190 to 250 Mev has been measured with the University of Illinois betatron. The scattered photons were detected in a lead-glass Čerenkov counter. The recoil dueterons were momentum-analyzed and detected by two scintillation counters. The observed c.m.s. cross sections in Thomson units of $2.35\times10^{-32}$ $cm^2/sr$ are, for a photon c.m.s. scattering angle of 140°, $0.879\pm0.10$ at 189 Mev and $0.751\pm0.11$ at 219 Mev and for a photon c.m.s. scattering angle of 110°, $0.943\pm0.13$ at 218 Mev and $1.47\pm0.26$ at 250 Mev. The cross section for neutral photo-pion production in deuterium was also measured to be $1.31\pm0.10\times10^{-30}$ $cm^2/sr$ for an incident 238-Mev photon and a scattered photon angle of 128° in the laboratory. The Compton cross sections were compared with dispersion theories and found to exhibit the expected rise with energy above 200 Mev. The moderately good agreement indicates that the photon-neutron scattering amplitudes are simply related to those of the proton through charge independence, and that the "impulse approximation" is valid.

* Supported in part by the U. S. Office of Naval Research.

**J10. Lewis Effect in Nuclear Resonance Reactions.*** D. G. COSTELLO, W. L. WALTERS,† J. G. SKOFRONICK, D. W. PALMER, W. E. KANE, AND R. G. HERB, *University of Wisconsin.*—A thick-target yield curve from a narrow resonance due to charged-particle bombardment exhibits a peak just above the resonance if the energy spread of the charged particles is

sufficiently small. This effect, first suggested by H. W. Lewis, is due to the process by which charged particles lose energy in passing through matter. Energy losses are in discrete jumps. Particles incident above the resonance energy may completely jump over a narrow resonance, whereas particles incident at the resonance energy all have a chance to interact. Thus there is a peak in the yield curve. Yield curves due to a monoenergetic beam for a resonance of infinitesimal width were determined by Monte Carlo calculations. They exhibit high peaks at the resonance energy. The area under the peak increases as the maximum and minimum allowable energy loss increases. The Lewis effect should therefore be most pronounced at high-energy resonances in targets of high atomic number.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
† Now at the University of Wisconsin, Milwaukee.

**J11. Observations of Lewis Effect in $Al^{27}(p,\gamma)Si^{28}$ Resonance at 992 kev.*** W. L. WALTERS,† D. G. COSTELLO, J. G. SKOFRONICK, D. W. PALMER, W. E. KANE, AND R. G. HERB, *University of Wisconsin.*—Thick-target yield curves from the $Al^{27}(p,\gamma)Si^{28}$ resonance at 992 kev were taken under a variety of conditions. By utilizing normal target techniques, peaks clearly indicating the Lewis effect were observed, but they disappeared after prolonged bombardment. By utilizing a technique in which evaporation during bombardment continuously replenishes the surface, peaks were consistently obtained. Peaks rising as much as 10% above the plateau height of the yield curve were observed several hundred ev above the resonance energy. A theoretical yield curve was determined from the coumputer calculated curve by taking into account finite energy resolution and nonzero resonance width. The peak in this curve was higher than any experimentally obtained. This is probably due to contaminants still present with continuous evaporation. The calculated yield curve also indicates that previous determinations of the resonance energy from thick-target yield curves may be in error.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
† Now at the University of Wisconsin, Milwaukee.

**J12. Multiple Coulomb Excitation with $O^{16}$ and $Ne^{20}$ Ions.*** J. S. GREENBERG, G. F. PIEPER, AND E. BISHOP, *Yale University.*—$O^{16}$ and $Ne^{20}$ ions with energies near the barrier have been used to Coulomb excite some of the higher-lying levels of the ground-state rotational band in the following odd $A$ and even-even nuclei: $Tb^{159}$, $Ho^{165}$, $Tm^{169}$, $Ta^{181}$, $Sm^{152}$, $Sm^{154}$, and $U^{238}$. In each case the majority of the gamma-ray transitions observed can be assigned to the de-excitation of the members of the ground-state rotational band which have been excited by up to 5th-order multiple-Coulomb excitation. For example in the case of $Tb^{159}$, in addition to the previously reported $7/2+$ and $5/2+$ states, there is evidence for the excitation of the following levels of the $K=3/2$ band: $9/2+$, $11/2+$, $13/2+$, $15/2+$, and $17/2+$. The positions of these states show small deviations from the interval rule for a simple rotor model. Gamma rays that can be attributed to direct excitation of high-lying levels in $Tb^{159}$ and $Ho^{165}$, have also been observed, and the possibility that these are vibrational excitations is being explored. Ion-gamma-ray coincidences were employed in the above experiments.

* This work has been supported by the U.S. Atomic Energy Commission.

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## FRIDAY AFTERNOON AT 2:00 p.m.

Social Sciences 122

(R. G. SACHS, presiding)

### *Theoretical Physics*

**K1. Modified Lee Models and the Field Theoretical Definition of Elementary Particle.** FRANCESCO CALOGERO,* *University of California, Berkeley* (introduced by Charles Zemach).—Exactly solvable models of field theory are introduced and discussed. In some of these models the physical states involve an infinite number of bare particles. Some solutions are also found, which depend in a nonanalytic way on the coupling constant. These solutions may appear as new "elementary particles." The field theoretical definition of "elementary particle" is then discussed. The renormalized coupling constants are always assumed to be smaller than some critical values (depending on the form factors of the models), thereby excluding any pathological feature (such as ghost states, etc.). In this paper only elementary particle states and bound states or scattering states involving one physical baryon and one boson are considered.

* Harkness Fellow, on leave of absence from Istitute Nazionale di Fisica Nucleare, Sezione di Roma, and Istitute di Fisica dell' Università, Roma, Italy.

**K2. On the Width of Narrow Spectral Lines.*** OTTO HALPERN,† *Lawrence Radiation Laboratory, Livermore.*—The width of narrow spectral lines for very long-lived emitters is lastly determined by the natural lifetime (absorption time) of quanta. In the limit of infinitely long lifetime of the emitters, the width of the spectral line is exclusively determined by the absorption time. This effect can be put into experimental evidence by surrounding a very long-lived emitter at various distances by strong absorbers, and then measuring the linewidth as a function of the distances from the emitter to the absorbers. Such arrangements are planned at this laboratory, where preparations for the reading of the effect are being carried out.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Consultant to the U. S. Atomic Energy Commission.

**K3. Intrinsic Excitation of Even-Even Nuclei.** TATUYA SASAKAWA, *University of California, Los Angeles.*—On the basis of previous work,[1] intrinsic excitations of the rotational levels of even-even nuclei and the intrinsic structure of the wave functions are investigated without using the Hamiltonian of the Bohr model. The rotational levels of negative parity are treated on the same basis as the levels of positive parity. The importance of the Coriolis interaction is stressed in connection with the $M1$-transition, say, between the bands $K=2^+$ and $K=0^+$. The method of analyzing the experimental data without using any model is developed. With this method we can get informaion about the intrinsic excitation in excited states of even-even nuclei. Examples are given for several nuclei.

[1] T. Sasakawa, Bull. Am. Phys. Soc. 6, 233 (1961).

**K4. Sum Rule for the Nuclear Photoeffect.** M. DANOS, *National Bureau of Standards.*—Because of the apparent constancy of high-energy cross sections, the expression for the integrated photon absorption cross section derived in reference 1 by means of dispersion relations contains divergent integrals. Thus, at least one more subtraction is required which results in the following: Let $d(E)$ be the real part of the forward scattering amplitude, $\sigma(E)$ the total photon absorption cross section, $D(E)=d_A(E)-Zd_p(E)-Nd_n(E)$, and $\Sigma(E)=\sigma_A(E)-Z\sigma_p(E)-N\sigma_n(E)$, where the indices $A$, $p$, $n$ refer to a nucleus, a free proton, and a free neutron, respectively. Then there holds

$$\int_0^\mu \sigma_A(E)dE=\frac{2\pi^2e^2\hbar}{Mc}\frac{NZ}{A}+\int_\mu^\infty [Z(\infty)-\Sigma(E)]dE +\mu\Sigma(\infty)+D(\infty).$$

Here $\mu$ is the threshold for meson production. This expression will converge if $\Sigma(E)$ approaches $\Sigma(\infty)$ sufficiently fast. The term $\mu\Sigma(\infty)$ can be estimated and is insignificant; $D(\infty)$ is unknown. The sum rule must therefore be regarded as a means of determining $D(\infty)$ from experiment. Presently available data seem to indicate that $D(\infty)$ is not too large.

[1] M. Gell-Mann, M. L. Goldberger, and W. E. Thirring, Phys. Rev. **95**, 1612 (1954).

**K5. Calculations of Spin Densities in Aromatic Free Radicals.** THOMAS H. BROWN, *Union Carbide Research Institute,* MARTIN KARPLUS, *Columbia University,* AND JOHN C. SCHUG, *Gulf Research and Development Company.*—The valence bond techniques developed previously for calculating the spin densities in charged unsubstituted even-alternant free radicals[1] have been extended to cases where substituents are present on the aromatic rings. In particular, the cases of toluene, meta-xylene, and para-xylene negative ions have been considered. Various approximations have been used to take into account the substituent(s). The results of the calculations are compared with the values of the proton hyperfine constants obtained from the ESR spectra of the various negative ion radicals. Comparison is also made with the results of molecular orbital calculations where available. The general usefulness of the valence bond method in treating systems of this type also is discussed.

[1] J. C. Schug, T. H. Brown, and M. Karplus, J. Chem. Phys. (to be published).

**K6. Electrostatic Variational Principles in the Calculation of Molecular Energy Levels.*** DAVID M. SCHRADER AND STEPHEN PRAGER, *University of Minnesota.*—Thomson's and Dirichlet's variational principles afforded upper and lower bounds, respectively, for the various electronic interaction integrals appearing in molecular energy calculations. A proper use of the two principles leads to a modified minimum energy principle in which not only the wave function, but also certain trial electric fields and potentials are varied to obtain a minimum in the total energy. The main advantage of this procedure is that the sixfold electronic interaction integrals that normally appear in molecular energy calculations are replaced by integrals over at most three coordinates, thus greatly simplifying the calculation. The total energy of the ground state of the hydrogen molecule was calculated for the wave function $\exp[a(\xi_1+\xi_2)]g(\eta_1)g(\eta_2)$, where $\xi$ and $\eta$ are elliptical coordinates, and $g(\eta)$ is completely open. The resulting binding energy was 3.568 ev, which compares favorably with the best SCF energy of 3.636 ev.[1]

* Work supported by the Air Force Office of Scientific Research.
[1] W. Kolos and C. C. J. Roothaan, Revs. Modern Phys. **32**, 219 (1960).

**K7. Pair Annihilation from the Bound System $H^-e^+$.** S. M. NEAMTAN, G. DARBWYCH, AND G. OCZKOWSKI, *University of Manitoba.*—The variational method has been applied to the problem of the binding of a positron to a negative hydrogen ion. A four parameter trial function has been employed of the form $\psi=\exp(-\alpha r_3-\beta r_{12}-\gamma r_3-\delta r_{13})+\exp(-\alpha r_3-\beta r_{13}-\gamma r_2-\delta r_{12})$, where the subscript 1 refers to the positron and the subscripts 2 and 3 to the two electrons, the proton being taken fixed at the origin. A binding energy of 0.228 ev was obtained against the most favored mode of dissociation into hydrogen plus positronium. Pair annihilation from the ground state of such $H^-e^+$ systems may be expected to contribute a principal component to the radiation from the annihilation of positrons in the alkali hydrides. The above function with best values of the parameters yields a mean life against two photon annihilation of about four times that of single positronium, the difference arising mainly out of spin considerations. The nature of the angular distribution of the annihilation radiation will be discussed.

**K8. Distribution Function of Striations from Exploding Wires.** WILLIAM M. CONN, *Kansas City, Missouri,* AND HEINRICH ARNOLD, *Würzburg, Germany.*—Distances of striations of about 50 characteristic patterns on glass slides obtained from exploded Al, Ag, Cu wires were combined to a distribution function. Although the total number of striations per pattern varies considerably with the material, the shape of the function is nearly equal. It means that there is a mechanism which produces in the vicinity of a striation a new one. The following model gives the same distribution function: A phase transition solid-liquid occurs during the explosion, this being a discontinuous event due to the statistics of thermodynamics. As a result, small droplets form in the solid. They grow as a function of time due to their higher resistance. Although the change of the infrared spectra of Al, Ag, Cu is complex and not yet investigated, with sufficient accuracy during the phase transition, one can argue roughly: The inner energy is greater in the liquid phase than in the solid one. Higher energy levels of the electrons will be occupied and absorption of radiation with lower frequency becomes more probable. Anomalous dispersion exists near these absorption lines. A rise in this coefficient means a considerable change in the corresponding optical constant. The droplet may act as an optical system, in comparison with the surrounding which emits infrared radiation. It can be focused on a spot. There, the available energy is greater and will raise the probability of a new phase transition solid-liquid. Standing waves may accelerate this event due to a periodicity in the wire represented, for example, by unduloids.

**K9. On the Nature of Electricity.** ERNEST COLTON, *Lockheed California Company* (introduced by F. L. Bouquet).—Two simple assumptions lead to an elementary physical picture of electricity. This introduces simplifications and clarifications in several areas of physics. A maximum upper bound for temperature of $3.55\times10^{32}$°K and a lower bound of $1.28\times10^{-30}$°K are determined. It is suggested that the concept of temperature loses its significance above $5.94\times10^{9}$°K. An experiment is suggested to verify one of the assumptions. It is indicated how it can be modified to experiment with gravitational waves. Planck's constant is given the geometric intrepretation of force because a human is biologically limited to sense accurately only wave phenomena—light and sound; he cannot resolve with unlimited accuracy the length-time areas implied by such ray-waves into their length and time components. (A static universe has neither light nor sound, nor does a time universe without space—both are unobservable.) The advantages of using this concept in a six-dimensional energy space are mentioned. In such a space beta-decay or density-change forces may have the form $mc^3a/v^3$ where $mc^3$ is the amount of energy changing in the ratio of acceleration divided by the square of the particle distortion velocity.

**K10. Metacalculus, Differential Formulation of the Integral Principle of Least Action, and "ω Particles."** JOSEPH G.

BARREDO, *C. S. I. C.*—The M.I.T. $10^{20}$-ev cosmic rays and Berkeley "$\omega$ particles" predicted by triondynamics (which in turn is based on the chronosuperconductivity effect) demonstrate[1] (a) M.I.T.-Berkeley findings cannot only change our galaxy's concept but our fundamental mathematical concepts as well; (b) the most striking feature in the development of geometry during the last 2000 years, i.e., the expansion of "geometry object" concept through topology is not enough. This object needs to be defined through the more general concept of charge (see 1958 International Mathematical Congress Presidential Address); (c) Planck-Einstein-de Broglie-Bohm's desire for a differential formulation of the integral principle of least action is satisfied by the fundamental equation of metacalculus: action $=dx/dt=dN/dt=N^{3}t^{-4}$ ($N$=number of charges, $t$=time) with which, $dx$ (the undefined most elementary concept of calculus and physics) is defined; (d) "$\omega$ particles" are neither $\omega$ (the number of virtual particles is $\infty$ and the number of actual particles is as large as our search makes it) nor particles, but a trion (spinning sufficiently fast to avoid charge fusion, thus being virtual and, of course, neutral), i.e., an all-body problem to be resolved by triondynamics, as predicted by the author at the 1960 Thanksgiving meeting.

[1] B. C. Maglić, L. W. Alvarez, A. H. Rosenfeld, and M. L. Stevenson, Phys. Rev. Letters 7, 178 (1961). J. G. Barredo, Rev. mex. fis. 10, 48 (1961).

**K11. "Crossing-Over" Phenomenon in Relation to the Isotopes.** N. EFREMOV, *600 West 142 Street, New York.*—A partial explanation of the mystery of isotopes can be achieved by employing the concept of the rule of 4 and the rule of 6 which have been developed.[1] The operation of these rules is clearly observed when we compare the sums of the mass differences between the atomic weights of the chief isotopes in the successive series of the chemical elements. For example, in the successive series of a triad of elements such as $Cl_{5}$-$Ar_{-1}$-K or $K_{1}$-$Ca_{5}$-Sc the first sum $(5-1)$ of the mass differences between the chief isotopes is equal to 4 and the second sum $(5+1)$ of the mass differences is equal to 6. This situation has been found to prevail almost universally. Consequently, for the chief isotopes in the series, Cl-Ar-K-Ca-Sc-Ti-V-Cr-Mn, and for those of the Br-Kr-Rb-Sr-Zr-Nb-Mo-Tc series, we have the following sums of the mass differences between every triad of the constituent elements:

Cl-Mn: 4 6 6 4
Br-Tc: 6 4 4 6

Comparison of these two series of numbers shows that here we have a phenomenon in some way analogous to the so called "crossing-over" phenomenon, particularly well known to biology. In fact, this really is a perfect classical example of "crossing-over" where the extreme pair of fours in the one series corresponds to the middle pair of fours in the second series, and where the middle pair of sixes in the first series corresponds to the extreme pair of sixes in the second.

[1] N. Efremov, Bull. Am. Phys. Soc. 4, 319 (1959).

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FRIDAY AFTERNOON AT 2:00 p.m.

Rosenwald 2

(R. H. HILDEBRAND, presiding)

## *High-Energy Physics*

**KA1. Bremsstrahlung Accompanying High-Energy $\pi$ Meson-Proton Collisions and the $\pi$-Meson Form Factor.** H. ÜBERALL, *University of Michigan.*—We calculate the bremsstrahlung emitted by high-energy charged $\pi$ mesons during their collisions with protons. General considerations show[1] that for small emission angles, the longitudinal momentum transfer can become very small, and the radiation accordingly will be produced largely "externally," so that a perturbation calculation is quite accurate, in spite of the fact that strong interactions are involved. The results depend on the complex phase shifts of elastic pion-proton scattering—we have obtained these by tentatively analyzing the 6.8- and 1.44-Bev data assuming imaginary phases and absence of spin flip—and, on the electromagnetic form factor of the pion in its dependence on the pion mass (rather than on the photon mass, which the pion-electron scattering measures). The shape of the form factor may thus be investigated experimentally for squared momentum transfers up to 10 $m_{\pi}^{2}$.

[1] L. D. Landau and I. Ja. Pomerancuk, Zhur. Eksptl'. i. Teoret. Fiz. 24, 505 (1953); E. L. Feinberg and I. Ja. Pomerancuk, Suppl. Nuovo cimento 3, 652 (1956).

**KA2. Three-Pion Resonances in $\pi^{+}+d$ Reactions.*** A. PEVSNER, R. KRAEMER, M. MEER, M. NUSSBAUM, C. RICHARDSON, P. SCHLEIN, R. STRAND, AND T. TOOHIG, *Johns Hopkins University*, AND M. BLOCK, A. ENGLER, R. GESSAROLI, A. KOVACS, AND C. MELTZER, *Northwestern University.*—At the present time, 700 candidates for the reaction $\pi^{+}+d\rightarrow p+p+\pi^{+}+\pi^{-}+\pi^{0}$ with a beam momentum of 1.23 Bev/$c$ have been examined in film from the Alvarez 72-in. chamber. Of these candidates, 160 fit the reaction with a $\chi^{2}\leq 6$ using the Berkeley PANG and KICK programs. A histogram of the effective mass of the three-pion system reveals 85 events in the region 740–800 Mev. The peak of the resonance is 4 standard deviations above phase space. A Dalitz plot of the events in the peak will be presented. The absence of this peak in the $n+p+\pi^{+}+\pi^{+}+\pi^{-}$ final state indicates that this is $T=0$ resonance. These results corroborate the $787\pm 15$ Mev resonance of Maglić, *et al.*[1] The data also indicate a second bump at about 550 Mev, but with only 17 events in the bump. Only a fraction of the film has been analyzed so far. Work is in progress on increasing the statistics and studying other reactions.

* Supported by the Office of Scientific Research, National Science Foundation, and Office of Naval Research.

[1] B. C. Maglić, L. W. Alvarez, A. H. Rosenfeld, and M. L. Stevenson, Phys. Rev. Letters (to be published).

**KA3. Total Cross Sections for $K^{\pm}$ Mesons on Protons from 4 to 20 Bev/$c$.*** E. W. JENKINS, W. F. BAKER, R. L. COOL, T. F. KYCIA, R. H. PHILLIPS, AND A. L. READ, *Brookhaven National Laboratory.*—The total cross section ($\sigma_{T}$) for $K^{\pm}$ mesons, on protons, in the $K$ momentum range 4 to 20 Bev/$c$ have been measured at the Brookhaven Alternating Gradient Synchrotron.[1] Secondary beams of particles produced at angles

of 4½° and 9° were used for the measurements in the 10–20 Bev/$c$ and 4–12 Bev/$c$ momentum ranges respectively. The beams were collimated and momentum-analyzed and then defined by scintillation counter telescopes. A velocity-selective Čerenkov counter,[2] having a resolution of $\Delta\beta/\beta \simeq 2\times10^{-4}$, labeled electronically the $K$ particles in the beam. The attenuation of the $K$-meson beam by a 10-ft long liquid hydrogen target was measured. It was found that $\sigma_T(K^+ + p)$ is constant ($\sigma_T \approx 18$ mb), within the experimental accuracy, from 4 to 20 Bev/$c$. $\sigma_T(K^- + p)$ decreases slowly from $\approx$25 mb at 4 Bev/$c$ to $\approx$22 mb at 20 Bev/$c$. Some implications of these results will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] For a recent compilation of data and references see, for example, L. Kerth, Revs. Modern Phys. 33, 389 (1961), and A. M. Wetherill, *ibid.* 33, 382 (1961).

[2] T. F. Kycia and E. W. Jenkins, Brookhaven National Laboratory Rept. BNL-5493 (unpublished).

**KA4. High-Frequency Limit of 15.1-Mev Electron Bremsstrahlung.*** H. E. Hall,† A. O. Hanson, and D. Jamnik,‡ *University of Illinois.*—The yield of photons at the high-frequency limit of the bremsstrahlung spectrum was investigated by means of the 15.1-Mev scattering resonance in carbon. A survey of the 0° yield from several elements indicated that the yield at the limit increased strongly with atomic number. Measurements of the 15.1-Mev isochromats from a thin thorium ($Z=90$) target at several angles are presented and compared with the available calculation. $1.61\pm0.16$ mb is obtained for the total cross section ($kd\sigma/Z^2dk$) at the tip, which is in reasonable agreement with available theoretical values.

* This work was supported in part by the Office of Naval Research.
† Now at the General Electric Company, King of Prussia, Pennsylvania.
‡ Visiting physicist, now returned to Istitut J. Stefan Ljubljana, Yugoslavia.

**KA5. Automatic Collection and Reduction of Data for Nuclear Spark Chambers.*** Herbert Gelernter,† *CERN, Geneva.*—A system is described which dispenses with the traditional use of photographic film for recording the data contained in the discharge of a nuclear spark chamber. Instead, the chamber itself is directly viewed by a television vidicon camera, whose output is digitized for direct input to a computer or for recording on magnetic tape. Preliminary experiments indicate that a measurement precision of 0.1% (i.e., to locate the center of a spark to 1 mm in a meter-wide chamber) will be easy to achieve with ordinary industrial vidicon tubes. The existence of currently available high resolution vidicons makes it likely that this figure can be substantially improved. By coupling the vidio system directly to an IBM 7090 computer, it is shown that the automatic collection and on-line analysis of 100 000 spark chamber events/day is probably feasible.

* This work has been jointly supported by the Ford Foundation and IBM Research.
† On leave from Thomas J. Watson Research Center, Yorktown Heights, New York.

**KA6. A Possible Means to Obtain Evidence Concerning Spin of the $K'$ Meson.** B. T. Feld* and D. B. Lichtenberg,† *CERN, Geneva.*—It is shown that antiproton-proton annihilation at rest into a $K'$ and $\bar{K}'$ meson can provide information about the spin of the $K'$ if a number of assumptions are justified. These assumptions are: (1) the $K'$ has spin either zero or one, (2) the annihilation occurs in an $S$ state, (3) the $K'$ and $\bar{K}'$ decay as free particles, (4) the background of annihilation events which cannot be distinguished kinematically from $K'\bar{K}'$ production is small. The method consists in showing that if the $K'$ has spin one, it is unlikely that the angular distributions will be isotropic with respect to all the angles specified by the production and decay of the $K'$ and $\bar{K}'$. The degree of anisotropy is not unique, but cannot vanish unless three relationships hold among the parameters specifying the interaction. If the $K'$ has spin zero, the angular distribution is isotropic. All of the assumptions are open to some question. Nevertheless, it may be possible to obtain some evidence about the spin of the $K'$ from the angular distributions, even if the assumptions are false.

* John Simon Guggenheim fellow. Present address: Department of Physics, M.I.T., Cambridge, Massachusetts.
† Supported by a grant from the National Science Foundation. Present address: Physics Department, Michigan State University, East Lansing, Michigan.

**KA7. Quasi-Elastic Peaks in High-Energy Nucleon-Nucleon and Pion-Nucleon Scatterings.*** S. D. Drell,† *CERN, Geneva,* and K. Hiida‡, *Argonne National Laboratory.*—A bump in the energy spectrum of inelastically scattered protons emerging from proton-nucleus collisions for incident energies in the range 9–25 Bev and for scattering angles of 20–60 mrad has been reported by Cocconi *et al.* at CERN. Their recent experiment on C and $CH_2$ shows a possible structure in the inelastic peak in the form of camel humps. Our purpose is to suggest a mechanism giving rise to the bump. This mechanism is the diffraction scattering of a pion in the cloud of the target nucleon. The main results of calculations for the conditions of observation at CERN will be presented. Further, we should like to suggest that there should be a quasi-electric diffraction peak in the process $\pi+N\rightarrow\pi+\pi+N$. The results of calculations will be compared with an experiment at CERN.

* Work performed in part under the auspices of the U. S. Atomic Energy Commission and in part by the U. S. Air Force through the Air Force Office of Scientific Research.
† On leave of absence from the Department of Physics, Stanford Universtiy, Stanford, California.
‡ On leave of absence from the Research Institute for Fundamental Physics, Kyoto University, Kyoto, Japan.

**KA8. Study of Pion-Hyperon Resonances by Dispersion Relations in the Unphysical Sheet.*** R. C. Hwa and D. Feldman, *Brown University.*—A method has been developed for studying dynamical resonances by taking into consideration resonance poles in the unphysical sheet. For a many-channel system, this involves diagonalizing the partial-wave $S$ matrix and examining the analyticity properties of the resultant eigenamplitudes. Specifically, for the two-channel, $I=1$, pion-hyperon system, we ignore the left-hand cuts, but take into account their effects by inserting a conjugate pair of resonance poles, the real part of whose positions is regarded as a parameter of the theory. The imaginary part is a measure of the resonance width, and is determined by dispersion relations in terms of the residues of the Born terms. The branching ratio is inferred from the orthogonal matrix that effects the diagonalization. The results indicate that, for even ($\Lambda$,$\Sigma$) parity, the width and branching ratio of $Y_1^*$ can be interpreted as a $\pi Y$ resonance in the $J=\frac{3}{2}$ state, provided $g_{\pi\Sigma\Sigma}$ is much smaller than $g_{\pi\Lambda\Sigma}$. No resonance is likely to occur in the odd ($\Lambda$,$\Sigma$) parity case.

* Supported in part by the U. S. Atomic Energy Commission.

**KA9. Interactions of 30-Bev Protons in Nuclear Emulsion.*** E. R. Goza, J. J. Loid, J. G. Parks,† and C. H. Tsao,‡ *University of Washington.*—About 1100 stars have been observed in a stack of Ilford G-5 emulsion of dimension $10\times30$ cm$^2$ and 600 $\mu$ thick which were exposed to the magnetically analyzed diffracted proton beam of the Brookhaven AGS. The average energy of the circulating proton beam was 30 Bev which agrees rather well with multiple scattering measurements of $30.9\pm1.6$ Bev made on 59 beam tracks. The average proton density in the plane perpendicular to the beam entering the emulsion was $5.5\times10^4$ protons per cm$^2$. On track scanning

was employed to obtain a total of 408.0 m (to date) and the mean free path neglecting single scatterings is 38.3±1.2 cm. A total of 11 probable elastic proton-proton scatterings have been found. Angular distributions of secondary particles will be presented as well as prong multiplicities, and elastic and inelastic proton-proton cross sections. Preliminary data indicate that the average prong multiplicity is somewhat higher than that at 23.5 and 28 Bev, an anisotropy exists in the angular distributions of the individual prong distributions.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and a grant from the National Science Foundation.
† Now at Lockheed Aircraft Corporation, Los Angeles, California.
‡ Now at the University of Chicago, Chicago, Illinois.

**KA10. $\pi^{\pm}+p$ Elastic Scattering at 30 Mev.*** D. E. KNAPP† AND K. F. KINSEY, *University of Rochester.*—Five new measurements for $\pi^{-}+p$ and three for $\pi^{+}+p$ serve to extend the angular range and accuracy of elastic pion proton differential cross sections at 30 Mev. These data combined with previous measurements at this energy provide a significant improvement in the accuracy of $S$ and nonresonant $p$-wave phase shifts. In the phase shift solution only the 3,3 phase shift is fixed by data at other energies. The results for the remaining phase shifts are: $\alpha_1=0.087\pm0.008$, $\alpha_3=-0.065\pm0.001$, $\alpha_{11}=0.051\pm0.007$, $\alpha_{13}=-0.042\pm0.004$, and $\alpha_{31}=-0.0082\pm0.0018$. Assuming a linear momentum dependence for the $S$-wave phase shifts, this solution gives a value for the scattering length difference $\alpha_1-\alpha_3=0.254\pm0.015$. The nonresonant $P$ waves follow the general trend of recent theoretical predictions which take into account the effect of a $\pi$-$\pi$ resonance on these phase shifts.[1]

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Douglas Aircraft Company, Inc., Santa Monica, California.
[1] S. C. Frautschi and J. D. Walecka, Phys. Rev. 120, 1486 (1960); J. Bowcock, N. Cottingham, and D. Lurie, Nuovo cimenta 19, 142 (1961).

**KA11. $K^{-}+P$ Interactions at 1.15 Bev/$c$.*** MARGARET ALSTON, L. W. ALVAREZ, P. EBERHARD,† M. L. GOOD,‡ W. GRAZIANO, H. K. TICHO,§ AND S. G. WOJCICKI, *Lawrence Radiation Laboratory, Berkeley.*—In a systematic study of 1.15-Bev/$c$ $K^{-}$ interactions in the Lawrence Radiation Laboratory 15-in. hydrogen bubble chamber we have analyzed the reactions $K^{-}+P$ going to $KN$, $KN\pi$, and $Y\pi$. For the three reactions $K^{-}+P\rightarrow\Sigma^{+}+\pi^{-}$, $K^{-}+P\rightarrow\Sigma^{-}+\pi^{+}$, and $K^{-}+P\rightarrow\Sigma^{0}+\pi^{0}$, the angular distributions and the cross sections (about 1.3 mb) are similar, which suggests that these reactions are proceeding predominantly through the $I=0$ channel. In the $\Sigma^{+}\pi^{-}$ reactions with $\Sigma^{+}\rightarrow P+\pi^{0}$, $\alpha\bar{P}$ equals 1.0±0.2, indicating that the polarization of the $\Sigma^{+}$ is close to 100%. From the analysis of our $KN\pi$ events and using the fact that the $K^{*}$ has isotopic spin $=\frac{1}{2}$, we have obtained cross sections of 1.4±0.3 for $K^{-}+P\rightarrow K^{*-}+P$ and 0.7±0.2 for $K^{-}+P\rightarrow K^{*0}+N$. Cross sections for $K^{-}+P\rightarrow K^{-}+P$ and $K^{-}+P\rightarrow\bar{K}^{0}+N$ will be presented at the meeting.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Presently at Laboratorie de Physique Atomique, College de France, Paris, France.
‡ Presently at University of Wisconsin, Madison, Wisconsin.
§ Presently at University of California at Los Angeles, Los Angeles, California.

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FRIDAY EVENING AT 7:00 p.m.

Quadrangle Club

(F. SEITZ presiding)

***Banquet of the American Physical Society***

After-dinner speech: **The Nature of Genetic Information.** GEORGE BEADLE, *The University of Chicago.*

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SATURDAY MORNING AT 9:30 a.m.

Mandel Hall

(H. L. ANDERSON presiding)

***Invited Papers***

**L1. Pion-Proton and Proton-Proton Interactions.** D. K. ROBINSON, *Brookhaven National Laboratory.* (30 min.)

**L2. Evidence for Two- and Three-Pion Resonances in Antiproton Annihilations.** B. MAGLIĆ, *Lawrence Radiation Laboratory.* (30 min.)

**L3. Recent Results with the Argonne Fast Chopper.** R. E. COTÉ, *Argonne National Laboratory.* (30 min.)

**L4. Analysis of Neutron Resonances.** E. LYNN, *Argonne National Laboratory and AERE, Harwell.* (30 min.)

SATURDAY MORNING AT 9:30 a.m.

Breasted Hall, The Oriental Institute

(M. G. INGRAM pending)

## *Semiconductors II*

**M1. Some Evidence for *p*-Type Silicon by Fluorine Doping.** R. E. EWING, *Shockley Transistor Unit, Clevite Corporation* (introduced by W. Shockley).—The anomalous presence of *p*-type layers has been observed occasionally in the course of repetitive preparation of epitaxial material on silicon slices by the hydrogen reduction of silicon tetrachloride. Several experiments have been performed which indicate that these *p*-type layers result from contamination introduced into the the gaseous phase. These experiments indicate that fluorine is the contaminant and suggest that fluorine, probably present in the lattice in the form of interstitial negative fluorine ions, may be acting as an acceptor to produce *p*-type layers. The *p*-type layers were produced from three materials containing fluorine: (1) silicon tetrafluoride was added to the silicon tetrachloride during depsition; (2) the hydrogen-silicon tetrachloride gaseous mixture was passed over hot Kel F grease; and (3) a silicon slice with an *n*-type epitaxial layer was heated in a stream of hydrogen containing cesium fluoride vapor. Further evidence that a new type of acceptor is involved in these experiments is given by the diffusion coefficient which was estimated to be about $5\times10^{-9}$ cm²/sec at 1200°C, a value 1000 times greater than boron. Further evidence of the high diffusion constant was demonstrated by the rapid out diffusion of the *p*-type doping agent at 1300°C from the silicon. These observations suggest that compounds containing fluorine should be avoided in epitaxial systems.

**M2. Effective Mobilities of Surface Carriers in Germanium.** WALTER A. ALBERS, JR., *Bendix Research Laboratories.*—Measurements of bulk and surface conductivities, Hall coefficients, and transverse and longitudinal magnetoresistance coefficients have been made on oriented near intrinsic (40 ohm cm at 295°K) *n*-type germanium. The surface coefficients are presented as a function of surface potential and are analyzed in terms of recent calculations of the effective surface mobilities[1] employing the low-field three-band theory of Petritz.[2] The theory is extended to include the longitudinal magnetoresistance case and an anisotropic conduction band. The effects of low-surface recombination velocities, which are inherent due to sample preparation techniques, are discussed. It is concluded that the longitudinal magnetoresistance affords a means of observing the effective surface mobility which is free of some of the ambiguities of interpretation experienced with Hall and transverse magnetoresistance data.

[1] R. F. Greene, D. R. Frankl, and J. N. Zemel, Phys. Rev. 118, 967 (1960).
[2] R. L. Petritz, Phys. Rev. 110, 1254 (1958).

**M3. Hall Coefficients and Resistivities of Tellurium Single Crystals.*** P. SKADRON AND V. A. JOHNSON, *Purdue University.*—Measurements of the Hall coefficients and resistivities of tellurium single crystals having varying impurity contents have been made in the temperature range from 77° to 400°K. The Hall coefficients were measured with the magnetic field parallel and perpendicular to the *c* axis of the crystal, and the resistivities with the current parallel and perpendicular to the *c* axis. Samples with carrier concentrations of roughly $10^{16}$/cm³ and $4\times10^{16}$/cm³ at 77°K have so far been investigated. The results obtained lead to the tentative conclusion that in the extrinsic temperature range the ansiotropy in both the Hall coefficient and resistivity tends to increase as the impurity content decreases. These results are consistent with those of Roth,[1] who reported a relatively high degree of anisotropy in very pure samples with a carrier concentration of about $1.5\times10^{14}$/cm³ at 77°K, and also the more recent data of Teutsch[2] *et al.*, who found essentially no anisotropy in the Hall coefficient above 77°K for very impure samples having around $10^{17}$ holes/cm³.

* Supported by Selenium-Tellurium Development Committee, Canadian Copper Refiners Limited, and American Smelting and Refining Company.
[1] H. Roth, J. Phys. Chem. Solids 8, 525 (1959).
[2] W. B. Teutsch, H. Roth, and H. T. Harper, Bull. Am. Phys. Soc. 6, 27 (1961).

**M4. Preparation of SnTe Single Crystals.** B. B. HOUSTON, R. F. BIS, AND E. GUBNER, *U. S. Naval Ordnance Laboratory.*—SnTe single crystals have been pulled from the melt by the Czochralski technique. They were pulled in an inert atmosphere using apparatus developed for pulling PbTe. The as-pulled crystals are *p* type with a carrier concentration of about $8\times10^{20}$/cm³ as computed from Hall data by means of a one-carrier formula. Small samples cut from the as-pulled crystals were brought to equilibrium at the Te- and Sn-rich limits of stability at 600°C and quenched using techniques developed by Brebrick.[1] If the Hall data on these samples are interpreted in the manner used by Brebrick and Allgaier for PbTe[1] the samples equilibrated at the Sn-rich limit of stability are *p* type with $1.8\times10^{20}$ carriers/cm³ or 50.2 at.% Te, and those equilibrated at the Te-rich limit were *p* type with $20\times10^{20}$ carriers/cm³ or 53.3 at.% Te. This interpretation seems more plausible than one based on a semi-metal model. If it is correct, the solidus field of SnTe is unusually wide and probably lies entirely on the Te-rich side of the stoichiometric composition. The wide range of stability should make it easy to check the validity of the assumptions used in this interpretation by comparing these results with those from other types of experiments—chemical analysis and density and lattice parameter measurements, for example. To date efforts to make use of other techniques have been hampered by restrictions on sample size imposed by the diffusion step in the preparation. Although quantitative agreement is poor, chemical analysis does indicate that the limits of stability are approximately as wide as those stated above. This work is still in progress.

[1] R. F. Brebrick and R. S. Allgaier, J. Chem. Phys. 32, 1826 (1960).

**M5. Electrical Properties of *p*-Type SnTe.** R. S. ALLGAIER AND P. O. SCHEIE, *U. S. Naval Ordnance Laboratory.*—We have analyzed Hall coefficient and resistivity data from measurements between 4.2 and 300°K on several SnTe samples using a one carrier model. On this basis the samples had hole concentrations between 1.8 and $20\times10^{20}$ cm³. The room-temperature resistivity, which was practically independent of carrier concentration, was $1.2\times10^{-4}$ ohm-cm. The Hall mobility therefore decreased from 420 to 30 cm²/v-sec with increasing carrier concentration. Corresponding values at 77°K were 1140 and 63 cm²/v-sec. The observed mobilities may be qualitatively explained by a combination of acoustical lattice and ionized impurity scattering, with due regard for the fact that the degenerate statistics makes the average carrier energy, and hence the scattering time, carrier-concentration dependent. Unpublished measurements on PbTe having between $10^{19}$ and $10^{20}$ holes/cm³ exhibit a similar mobility behavior. For the

SnTe samples with $1.8\times10^{20}$ holes/cm³, the Hall coefficient was about 40% higher at 300° than at 77°K, again similar to the behavior in $p$-type PbTe. However, as the carrier concentration increased, this ratio decreased, (in PbTe it increases at least up to $1.5\times10^{20}$ holes/cm³) and was approximately unity at $20\times10^{20}$ holes/cm³. The behavior in both materials can be explained as a two-band effect.

**M6. Epitaxial PbS Films: Electrical Properties.** J. D. JENSEN AND J. N. ZEMEL, *U. S. Naval Ordnance Laboratory.*—Thin films of lead sulphide have been prepared by epitaxial deposition onto cleaved surfaces of NaCl. The thickness of the films ranged between 0.5 and 1.5 $\mu$. Hall coefficient measurements showed that the films could be either $n$- or $p$-type with carrier concentrations of the order of $10^{18}$/cm³. Hall mobilities at room temperature varied from 2 to 300 cm²/v-sec for both types; a value of 60 cm²/v-sec being obtained on the average. The highest mobility found is quite comparable to bulk mobility of 4–500 cm²/v-sec and the average mobility is about an order of magnitude higher than the usual evaporated PbS films. Measurements were carried out in the temperature range from 77° to 300°K. At high temperatures, the mobility varied asymptotically as $T^{-5/2}$. At low temperatures an approximately temperature-independent mobility appeared which severely limited the magnitude of the mobilities.

**M7. Thermal Conductivity in Ge-Si Alloys at High Temperatures.*** G. CODY, B. ABELES, AND D. BEERS, *RCA Laboratories.*—The thermal conductivity of several Ge-Si alloys was determined in the temperature range 300° to 1200°K. A strikingly large decrease in the lattice thermal conductivity in the entire temperature range was found upon alloying. The temperature dependence and magnitude of the thermal conductivity can be obtained from current theory[1,2] if it is modified to permit the dependence of anharmonic scattering on alloy composition. Justification for his dependence is given in terms of second-order processes involving simultaneous two-phonon impurity scattering and three-phonon anharmonic scattering.[3] A photon contribution to the thermal conductivity has been observed in a 68% alloy doped to $3\times10^{19}$ carriers. The temperature dependence and magnitude of this additional conduction mechanism is in fair agreement with theory.[4] The low thermal conductivity of the Ge-Si alloys makes these materials useful for high temperature thermoelectric power generation. Data are given for a couple operating over a 900°K temperature range with a power-conversion efficiency of 10.0%.

* Work supported by Naval Bureau of Ships.

[1] P. G. Klemens, Phys. Rev. 119, 507 (1960).
[2] J. Callaway and H. C. von Baeyer, Phys. Rev. 120, 1149 (1960).
[3] P. Caruthers, Revs. Modern Phys. 33, 92 (1961).
[4] L. Genzel, Z. Phys. 135, 177 (1953).

**M8. Transient Effects in Peltier Coolers.** A. D. REICH, T. ARAI, AND J. R. MADIGAN, *Borg-Warner Corporation.*—Previous calculations of transient effects in Peltier coolers by Reich *et al.*[1,2] were made under the restrictive assumption that the Peltier voltage was not temperature dependent. One consequence of these calculations is a limit to the size of the thermal cold spikes which are obtained for arbitrarily large currents. If the voltage is allowed to change with temperature one finds, to the same order of approximation, that the restriction on the size of the thermal spikes is more severe. The thermal conductivity of some $Bi_2Te_3$ alloys was determined by the method suggested in the first article. The agreement with other methods is surprisingly good since the transient response for this model should only be qualitatively correct.

[1] A. D. Reich and J. R. Madigan, J. Appl. Phys. 32, 294 (1961).
[2] T. Arai and J. R. Madigan, J. Appl. Phys. 32, 609 (1961).

**M9. Rotating Sample Method for Measuring the Hall Mobility.** F. M. RYAN, *Westinghouse Research Laboratories.*—A simple apparatus is described for measuring Hall mobilities. The sample to be measured is rotated in an external magnetic field. The sample thus "sees" an ac magnetic field and ac magnetic field Hall techniques may be used. Methods will be decreased for obtaining dc or ac Hall output voltages. Probe misalignment voltages are rejected by this technique as they are in a standard ac magnetic field method. By using a dc magnetic field, equipment design is simplified and the ac magnetic field Hall technique may be extended to the region of high magnetic fields. Some results will be given of rotating sample Hall mobility measurements on low mobility pressed and sintered semiconductors.

**M10. Conductivity Modulation by Excess Carriers in Semiconductor Filaments and the Theory of the Double-Base Diode.** D. SCHARFETTER AND A. G. JORDAN, *Carnegie Institute of Technology.*—A solution for the flow of added carriers in semiconductor filaments, based on the assumption of quasi-charge neutrality and absence of trapping effects has been developed. A double-base diode structure is selected to investigate the transient and steady state effects associated with conductivity modulation, because in a device of this nature conductivity modulation by injected carriers proves to be strong. Reactive effects (both inductive and capacitive) in $p$-$n$ junction diodes, previously reported by other workers, are easily derived as a special case of the more general structure here studied. For an intrinsic semiconductor it is possible to obtain a general solution of the problem in the form of a Fourier series in terms of device and material parameters. If recombination is neglected the problem is greatly simplified and the device may be fairly accurately represented by an RLC equivalent circuit. The static characteristics of the double-base diode and its general transient effects predicted from the theory are in fair agreement with those observed experimentally.

**M11. Theory of Ion Drift in a $p$-$n$ Junction.** H. REISS AND F. A. LEHRER, *Atomics International.*—Pell[1] has described the drift of lithium ions in a $p$-$n$ junction under reverse bias. Besides performing experiments, Pell performed a mathematical analysis of a motion of such lithium $p$-$n$ junctions. In order to minimize the mathematical complexity, consideration was limited to certain extreme situations which were nevertheless of major importance for the measurement. A more complete analysis of the equations of motion of such a lithium $p$-$n$ junction has been performed by the authors. As a result, it is possible to describe the time dependence of all the relevant phenomena. In particular, the form of the lithium distribution (approximately a sinh function) has been derived as a function of time. Descriptions also are available for the motion at the junction under zero bias.

[1] E. N. Pell, J. Appl. Phys. 31, 291 (1960).

SATURDAY MORNING AT 9:30 a.m.

Judd 126

(M. HAMERMESH presiding)

## *Invited Papers in Theoretical Physics*

**N1. Relativistic Particle Systems.** L. FOLDY, *Case Institute of Technology.* (30 min.)

**N2. Some Fundamental Relativistic Problems of a Classical Charge and Its Radiation.** F. ROHRLICH, *State University of Iowa.* (30 min.)

**N3. Applications of Random Functions to Statistical Mechanics.** A. J. F. SIEGERT, *Northwestern University.* (30 min.)

**N4. $K^-$ Scattering by Nuclei.** D. G. RAVENHALL, *University of Illinois.* (30 min.)

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SATURDAY MORNING AT 9:30 a.m.

Eckhart 133

(P. J. PRICE presiding)

## *Metals and Semi Metals*

### *Invited Papers*

**O1. Phonon-Drag Thermoelectricity in Metals.** F. J. BLATT, *Michigan State University.* (30 min.)

**O2. The Fermi Surface in Metals.** A. V. GOLD, *University of Iowa.* (30 min.)

### *Contributed Papers*

**O3. Lattice Conductivity of Copper Alloys.*** W. B. PENNEBAKER AND P. LINDENFELD, *Rutgers University.*—Measurements at liquid helium temperatures have been made of the thermal conductivity of a number of solid solutions in copper. Four different solute elements were used. The residual resistivities ($\rho_0$) varied from 0.3 to 12.5 $\mu\Omega$ cm. The electronic conductivity was subtracted using the Wiedemann-Franz law, and the lattice conductivity Kg was plotted as $Kg/\rho_0$ vs $T/\rho_0$. On this graph the data for all specimens lie close to a universal curve. Similar behavior was found previously by Zimmerman[1] for silver alloys with higher resistivities, and explained using the Pippard theory of electron-phonon interaction.[2] Our experiments show several new features which are in accord with more exact calculations based on Pippard's theory. For the smaller residual resistivities Kg is dominated by the transverse modes. In this region the magnitude of Kg increases approximately linearly with $1/\rho_0$ and the temperature dependence is nearly $T^3$.

* Supported by the National Science Foundation.
[1] J. E. Zimmerman, J. Phys. Chem. Solids 11, 299 (1959).
[2] A. B. Pippard, Phil. Mag. 46, 1104 (1955).

**O4. Magnetic Dependence of Phonons in Metals.** MICHAEL J. HARRISON, *Michigan State University.*—The dependence on magnetic field of the energies of longitudinal phonons in a metal has been investigated by studying the change in electronic screening arising from the presence of the field. The dependence of the screening on magnetic field is conveniently described through an inverse dielectric tensor characterizing the electron gas. The tensor components, which are dependent on wave vector, frequency, and magnetic field, have been obtained by employing the semiclassical collisionless Boltzman equation and a self-consistent field. The result obtained shows an increase in the frequency of longitudinal phonons which is proportional to the square of the field in the limit of long wavelengths and suitable fields. For smaller fields a component oscillatory in reciprocal field may exist. Experimental verification[1] and extensions are discussed.

[1] A. A. Galkin and A. P. Koroliuk, J. Exptl. Theoret. Phys. (U.S.S.R.) 34, 1025 (1958).

**O5. Magnetoacoustic Measurements in Silver, Copper, and Gold at 200 to 350 Mc.*** H. V. BOHM AND V. J. EASTERLING, *Wayne State University.*—Further magnetoacoustic measurements are reported on all three noble metals[1] with both transverse and longitudinal sound waves at frequencies up to 350 Mc. Plots of the ultrasonic pulse height, $h$, vs the reciprocal of the magnetic field strength, $1/H$, show 15 or more maxima and minima for several orientations in each metal. The Fermi surface dimensions calculated from the periods in $1/H$ of the magnetoacoustic oscillations are interpreted in terms of the Pippard type Fermi surface model, and details of the Fermi surface topolgy in some regions are presented. Some anomalous results obtained with sound propagated along the 111 direction are discussed. The positions of pulse height extrema in the $h$ vs $1/H$ plots are compared with theory.[2]

* This research was supported by the United States Air Force through the U. S. Air Force Office of Scientific Research.
[1] R. W. Morse, A. Myers, and C. T. Walker, J. Acoust. Soc. Am. 33, 699 (1961).
[2] M. H. Cohen, M. J. Harrison, and W. A. Harrison, Phys. Rev. 117, 937 (1960).

**O6. Ultrasonic Attenuation Measurements in Aluminum.*** G. N. KAMM AND H. V. BOHM, *Wayne State University.*—Magnetoacoustic oscillations of the ultrasonic attenuation in ultra-high purity aluminum single crystals have been studied at 4.2°K and at frequencies between 200 and 350 Mc. Three crystal samples were prepared with opposite faces accurately parallel to the (100), (110), and (111) planes. Longitudinal sound waves were propagated perpendicular to the sample faces while a variable magnetic field was rotated in the plane of the faces. The precision of the measurements permits a

more detailed comparison with the free electron model Fermi surface due to W. A. Harrison[1] than earlier work by B. W. Roberts.[2] The topology of the second zone of this simple model is confirmed in considerable detail. A variety of oscillations is observed at all angles, and interpreted as central orbits, off-center orbits, and orbits in the third zone. The rf system, sample holder, and automatic recording system used in the measurements will be described briefly.

* This research was supported by the United States Air Force through the Air Force Office of Scientific Research.
[1] W. A. Harrison, Phys. Rev. 116, 555 (1959).
[2] B. W. Roberts, Phys. Rev. 119, 1889 (1960).

**O7. Magnetoacoustic Determination of the Fermi Surface in Cadmium.*** J. D. GAVENDA AND B. C. DEATON,† *The University of Texas.*—We have measured the attenuation of ultrasonic waves in a single crystal of cadmium at liquid helium temperatures as a function of magnetic field in order to determine the topology of the Fermi surface. Oscillatory variations in attenuation with as many as 25 successive maxima were observed. The momentum of the conduction electrons was calculated from the period in $1/H$ for sound propagated along the [0001], [10$\bar{1}$0], and [$\bar{1}$2$\bar{1}$0] axes. Compressional waves having frequencies between 20 and 100 Mc/sec were used. The results, which are similar to those of Galkin and Korolyuk[1] in zinc, will be compared with the model proposed by Harrison.[2]

* Supported in part by the National Science Foundation and the Office of Naval Research.
† Texas Instruments Fellow.
[1] A. A. Galkin and A. P. Korolyuk, Soviet Phys.—JETP 11, 1218 (1960).
[2] W. A. Harrison, Phys. Rev. 118, 1190 (1960).

**O8. Cyclotron Resonance in Bi Single Crystals at 36 kMc.** Y. H. KAO, *Columbia University and IBM Watson Laboratory,* AND J. I. BUDNICK AND S. H. KOENIG, *IBM Watson Laboratory.*—Cyclotron resonance experiments of the Azbel and Kaner type[1] were done at temperatures near 2°K at microwave frequencies of approximately 36 kMc on Bi single crystals with estimated $\omega\tau$ of about 20. The ansiotropic cyclotron masses of the conduction electrons are found to be in close agreement with previous results of Aubrey[2] and Chambers and of Galt *et al.*,[3] using Shoenberg's model of three ellipsoids. Evidence of a hole is further confirmed by the presence of a carrier with rather isotropic cyclotron mass ($m^* \sim 0.22 m_0$) in the trigonal plane. Additional resonances are observed which seem to indicate the presence of a third carrier of density of state mass around $0.04\ m_0$. A partial study of these resonance lines was made by Aubrey and these lines were interpreted by him to be either the result of a light hole resonance or due to a spin resonance transition. Some discussion will be given of our interpretation of these resonance lines and of the variations in reported cyclotron mass values for Bi.

[1] M. Ia. Azbel and E. A. Kaner, Soviet Physics—JETP 5, 730 (1957).
[2] J. E. Aubrey and R. G. Chambers, J. Phys. Chem. Solids 3, 128 (1957); J. E. Aubrey, J. Phys. Chem. Solids 19, 321 (1961).
[3] J. K. Galt, W. A. Yager, F. R. Merritt, B. B. Cetlin, and A. D. Brailsford, Phys. Rev. 114, 1396 (1959).

**O9. de Haas-van Alphen Effect in Bismuth-Tellurium Alloys.*** DANIEL WEINER, *Hughes Research Laboratories* (introduced by J. M. Richardson).—De Haas-van Alphen measurements have been made on pure bismuth and several bismuth-tellurium alloys. It is found that the observed variation of extremal cross section and cyclotron effective mass with tellurium concentration and magnetic field orientation can be interpreted using a special case of Cohen's nonellipsoidal model of bismuth. The results indicate that there is a thermal energy gap between the conduction and valence band of about 0.046 ev in agreement with various optical experiments and that there are six electron "ellipsoids." The results also agree with a model for the hole band involving one light hole ellipsoid and one heavy hole ellipsoid and are used as evidence against some other possible models for the hole band.

* Supported in part by a grant from the National Science Foundation. This work was done while the author was a Bell Telephone Laboratories Fellow at the University of Chicago; a version was submitted as a thesis to the faculty of the University of Chicago.

**O10. Infrared Absorptance of Single Crystal Antimony.** C. NANNEY, *University of Chicago.*—The absorptance of antimony single crystals has been measured at room and helium temperatures in the region 2 to 18 $\mu$ using plane polarized radiation. Two distinct absorptance maxima are observed. One is located at 5.7 $\mu$ for a binary crystal direction normal to the surface and the electric field vector parallel to the trigonal axis. The second is located at 10.6 $\mu$ for the binary normal and the electric field vector parallel to the bisectrix axis. The maximum with the trigonal direction normal is polarization independent and occurs at 10.6 $\mu$ as expected. The positions of the maxima are essentially temperature independent. These absorptance maxima are interpreted as "dielectric anomalies."[1] These data are discussed in terms of the effective masses of the carriers and their densities.

[1] W. S. Boyle, A. D. Brailsford, and J. K. Galt, Phys. Rev. 109, 1396 (1958).

**O11. Galvanomagnetic Effects and Band Structure of Undoped and Tin-Doped Antimony.*** S. EPSTEIN, *U. S. Army Signal Research and Development Laboratory,* AND H. J. JURETSCHKE, *Polytechnic Institute of Brooklyn.*—Room temperature resistivities, Hall coefficients, and low-field magnetoresistivities for unworked, cast, oriented, single crystal rods of 0.8% and 0.2% tin-doped and pure antimony are presented, and the data are interpreted in terms of two threefold sets of tilted mobility ellipsoids for the valence and conduction bands. The analysis for pure antimony, in essential agreement with that obtained earlier[1] from data on differently grown and prepared crystals, yields a well-defined anisotropic hole band structure, but allows two alternatives for the electrons. The alloy data are compatible with the same structure upon isotropic scaling of each band's mobilities and assignment of unequal carrier densities. The numbers so derived show that each tin atom removes 0.3 carrier and that the hole band is three times as dense as the electron band. Using Shoenberg's[2] masses, the band edge overlap is 0.42 ev.

* The work at P.I.B. was partly supported by O.N.R.
[1] S. J. Freeman and H. J. Juretschke, Phys. Rev. (to be published).
[2] D. Shoenberg, Proc. Roy. Soc. (London) **A246**, 1 (1952).

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## SATURDAY MORNING AT 9:30 a.m.

Social Sciences 122

(C. P. BROWNE presiding)

### *Nuclear Reactions II*

**P1. Elastic Scattering of Alpha Particles by $O^{16}$ from 10 to 19 Mev.*** M. K. MEHTA, W. E. HUNT, AND R. H. DAVIS, *Florida State University.*—The yield of alpha particles elastically scattered from $O^{16}$ has been measured as a function of alpha particle bombarding energy in range 10 to 19 Mev. At least twenty-two resonances are resolved in the excitation

curves with observed level widths as large as 0.3 Mev. Detailed angular distributions have been taken at bombarding energies of 9.92, 11.97, 13.37, 15.20, 17.22, 18.30, and 18.90 Mev; the distribution at 18.30 Mev is in agreement with that of Correlli, *et al.*[1] In the vicinity of 18.3 Mev, prominent resonance structure was observed and the angular distribution at 17.22 Mev is rather different from the distributions at 18.3 and 18.9 Mev. All of the angular distributions exhibit strong diffraction patterns. The number of maxima and minima increase with increasing energy and all angular distributions exhibit strong backward peaking.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] Corelli, Bleuler, and Tendam, Phys. Rev. 116, 1184 (1959).

**P2. Measurement of the $O^{16}(n,p)N^{16}$ Relative Cross Sections between 11 and 19 Mev.** R. W. Stooksberry and J. A. De Juren, *Bettis Atomic Power Laboratory*, and M. Wallis, *Los Alamos Scientific Laboratory.*—A previously undetermined peak in the $O^{16}(n,p)N^{16}$ relative cross sections near 11.8 Mev was obtained in the course of this measurement. An earlier measurement by Martin[1] extended to a minimum energy of 12.5 Mev and therefore did not observe the above mentioned peak. The agreement above 12.5 Mev is reasonably good. Gas targets, 1 cm in length, were bombarded by positive ions accelerated by 3 Mev accelerators[2] utilizing both the $T(n,n)He^4$ and $D(t,n)He^4$ reactions. The oxygen was contained in a Dioxane liquid scintillator, which was irradiated in various geometrically shaped holders and subsequently transferred to a $4\pi B$ counting system.[3]

[1] H. C. Martin, Phys. Rev. 93, 498 (1954).
[2] This work was performed using the Los Alamos Physics Department Van de Graaff accelerators in conjunction with Los Alamos Personnel and through the courtesy of Dr. Ben Diven.
[3] J. A. DeJuren and R. W. Stooksberry, Phys. Rev. 120, 901 (1960).

**P3. The Reaction $O^{18}(\alpha,n)Ne^{21}$.** J. K. Bair and H. B. Willard, *Oak Ridge National Laboratory.*—The total absolute $(\alpha,n)$ reaction cross section of $O^{18}$ has been measured for $E_\alpha = 2.4$ to 5 Mev using the large 1.5-m-diam graphite sphere[1] as the neutron detector. Targets consisted of tantalum with a surface layer anodized in high purity $H_2O^{18}$, with thicknesses less than 2 kev (for 2.5-Mev alpha particles) for some measurements. Absolute cross sections were obtained using $O^{18}$ gas. The efficeincy of the graphite sphere was determined with the aid of a radium-beryllium neutron source calibrated by the Bureau of Standards. Approximately twenty-five resonances, ranging in width from 5 to 150 kev, have been found. A preliminary value of the absolute cross section at the peak of the resonance at 3.19 Mev ($\Gamma = 80$ kev) is $109 \pm 25$ millibarns. As a check on the energy calibration the $B^{10}(\alpha,n)N^{13}$ resonance near 1.5 Mev was found at $1.507 \pm 0.004$ Mev. This value is slightly lower than the previous value[2] obtained from the $B^{10}(\alpha,p\gamma)C^{13}$ reaction.

[1] R. L. Macklin, J. Nuclear Instr. 1, 335 (1957).
[2] D. A. Bromley, E. Almqvist, H. E. Gove, A. E. Litherland, E. B. Paul, and A. J. Ferguson, Phys. Rev. 105, 957 (1957).

**P4. Energy Levels at 9.9 Mev and 10.8 Mev in Mg.*** P. Axel, F. T. Kuchnir, H. W. Kuehne, K. Min, N. Stein, and D. C. Sutton, *University of Illinois.*—Two excited states were identified by observing the resonance fluorescence by natural Mg of 9.9 Mev and 10.8 Mev monochromatic photons. The existence of these two levels may well explain the different energies (10.5 Mev,[1] 10.15,[2] and 10.6 Mev[3]) previously assigned to a single level in $Mg^{24}$. Once the bremsstrahlung monochromator used with the Illinois 25-Mev betatron is calibrated, the energies of levels observable with resonance fluorescence should be obtainable to within 20 kev. To aid in this calibration, it would be extremely useful to have very precise energy values for these or comparable excited states.

* This work is supported by the joint program of the Office of Naval Research and the Atomic Energy Commission.
[1] M. Langevin and A. Bussière de Nercy, J. phys. radium 20, 831 (1959).
[2] R. A. Tobin, Phys. Rev. 120, 175 (1960).
[3] F. D. Seward, UCRL 5778 (unpublished).

**P5. Comparison of the $Al^{27}(p,\alpha)Mg^{24}$ and $Mg^{24}(\alpha,p)Al^{27}$ Q values.*** W. E. Dorenbusch† and C. P. Browne, *University of Notre Dame.*—Discrepancies in a number of closed nuclear reaction cycles have been reported[1] in which the suspect nuclear reactions involve alpha particles. The present investigation was prompted by the marked disagreement in previous measurements[2–4] of the $Al^{27}(p,\alpha)Mg^{24}$ and $Mg^{24}(\alpha,p)Al^{27}$ ground state $Q$ values. The ground state groups from the $Al^{27}(p,\alpha)Mg^{24}$ and $Mg^{24}(\alpha,p)Al^{27}$ reactions were analyzed with a broad-range spectrograph. Thin evaporated targets were used. The $Q$ value of the $Al^{27}(p,\alpha)Mg^{24}$ reaction was found to be in excellent agreement with that of the inverse reaction. The ground state $Q$ values were determined as $1.598 \pm 0.003$ Mev and $-1.598 \pm 0.005$ Mev, respectively, on the basis of a $Po^{210}$ alpha particle energy of 5.3056 Mev. Resonance effects were observed which could account for the previous discrepancy.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Summer Fellow.
[1] T. T. Scolman, K. S. Quisenberry, and A. O. Nier, Phys. Rev. 102, 1076 (1956).
[2] D. M. Van Patter, A. Sperduto, P. M. Endt, W. W. Buechner, and H. A. Enge, Phys. Rev. 85, 142 (L) (1952).
[3] D. J. Donohue, K. W. Jones, M. T. McEllistrem, and H. T. Richards, Phys. Rev. 89, 824 (1953).
[4] S. G. Kaufmann, E. Goldberg, L. J. Koester, and F. P. Mooring, Phys. Rev. 88, 673 (1952).

**P6. Angular Distributions of the Reactions $Al^{27}(p,\alpha_0)Mg^{24}$ and $Al^{27}(p,\alpha_1)Mg^{24}$ from 10 to 12 Mev.*** K. L. Warsh, H. R. Blieden, and G. M. Temmer,† *Florida State University.*—The reactions $Al^{27}(p,\alpha_0)Mg^{24}$ and $Al^{27}(p,\alpha_1)Mg^{24}$ were studied at 10.0, 10.5, 11.0, 11.5, and 12.0 Mev. The alphas were detected with junction counters thick enough to stop the alphas but thin enough not to detect the full energy of the protons. The shapes of the angular distributions were observed to change rapidly with beam energy. Some of these show large forward or backward peaking. An excitation curve will be presented; further work is in progress for higher excited states.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† Also DTM, Carnegie Institution of Washington.

**P7. $(n,p)$ and $(n,\alpha)$ Reactions in $Si^{28}$.*** T. W. Bonner, B. Mainsbridge, and T. A. Rabson, *Rice University.*—The $Si^{28}(n,p)Mg^{25}$, $Q = -2.66$ Mev and $Si^{28}(n,\alpha)Al^{25}$, $Q = -3.87$-Mev reactions have been observed in a silicon solid-state detector with a barrier depth equivalent to the range of a 7.5-Mev proton. An excitation curve for the two reactions has been measured between neutron energies of 4.6 and 8.6 Mev with an energy spread of 80–30 kev. Below 6 Mev, both reactions are strongly inhibited by the coulomb barrier and the ground state transitions are dominant. The total $(n,p)$ cross section rises to a maximum at $E_n = 7$ Mev while the $(n,\alpha)$ cross section rises steadily with energy. At $E_n = 8.5$ Mev, transitions to four levels of $Mg^{25}$ and nine of $Al^{25}$ were observed, the $(n,p)$ total cross section exceeding the $(n,\alpha)$ by a factor of 1.5. Because of the high level density of $Si^{29}$ and a 30-kev energy resolution, many levels were not observed by 40% variations in the cross section indicate strong resonant structure. Background reactions from $Si^{30}(n,\alpha)Mg^{27}$, $Q = -0.017$ Mev have also been observed.

* Supported in part by the U. S. Atomic Energy Commission.

**P8. Properties of Excited States of $P^{31}$ from the $Si^{30}(p,\gamma)$ Reaction.*** Gale I. Harris and L. W. Seagondollar, *Uni-*

*versity of Kansas.*—The excitation curve for gamma rays from natural silicon bombarded by protons of energy 975 to 1840 kev has been remeasured. Gamma ray spectra clearly show that the resonances at $E_p=1203$, 1323, 1390, 1398, 1480, and 1488 kev are due to $Si^{30}$. The decay modes of the intermediate levels are in agreement with earlier work[1] except for the 4.26-Mev level. Decay of the 1203 resonance shows the 4.26 level decays mostly to the ground state. The 4.2-Mev gamma ray is found to be in coincidence with itself. It must represent both members of the cascade from the 8.45-Mev level through the 4.26 level. 66% of the radiation from the 1480 kev resonance goes to the ground state with an angular distribution $W(\theta)=1-(0.39\pm0.03)P_2$. Assuming $M1$, $E2$ mixing, $\frac{3}{2}+$ assignment is made. Further angular distribution, coincidence, and spectra measurements are planned using separated $Si^{30}$.

* Supported in part by the National Science Foundation and the Office of Naval Research.
[1] Broude, Greene, and Willmott, Proc. Phys. Soc. (London) 72, 1097 (1958).

**P9. Decay Schemes and Properties of the Two States in $Ca^{40}$ Near 9.87 Mev.*** L. W. SEAGONDOLLAR, L. KASTURI RANGAN,† RICHARD A. MOORE, AND GALE I. HARRIS, *University of Kansas.*—The two closely spaced resonances[1] in the $K^{39}(p,\gamma)$ reaction near 1566 kev proton energy have been measured to be at $1575.5\pm1$ and $1580\pm1$ kev. Both resonances exhibit strong transitions to the $0^+$ first excited state and ground state. Relative intensities and angular distributions were measured for both resonances. An assignment of $2^+$ is made for the upper level. Arguments will be presented which support $J=1$ for the lower level. Comparisons with the Weisskopf estimates will be made. Yield measurements give $\omega\gamma=0.46$ and 0.51 ev ($\pm30\%$) for the lower and upper resonances, respectively. Alpha yield measurements gave $\sigma(p,\alpha)\leq68$ microbarns. Partial widths will be discussed.

* Supported in part by the NSF and the ONR.
† Now at the Agricultural and Mechanical College of Texas.
[1] R. L. Zimmerman and M. K. Moe, Bull. Am. Phys. Soc. 6, 47 (1961).

**P10. Nuclear Resonant Absorption of Gamma Rays from the 1576-Kev Resonance in the $K^{39}(p,\omega)Ga^{40}$ Reaction.** L. KASTURI RANGAN,† GALE I. HARRIS, AND L. W. SEAGONDOLLAR, *University of Kansas.*—Resonant absorption has been observed in CaO and Ca metal at the proton capture resonance of 1575.5 kev.[1] With an experimental aperture of 1.2° an absorption dip of 1.7° was observed. Rough hand calculations indicate a total level width of 140 ev, a proton width of nearly 140 ev, and, assuming $J=1$, a radiation width for the transition to the ground state of $1.4\pm0.3$ ev. The results of more accurate calculations will be presented. A $2^-$ assignment is considered very unlikely on the basis of the radiation width and $2^+$ is considered improbable due to the proximity of the $2^+$ level at 1580 kev. A $1^+$ is slightly favored over $1^-$ by the observed partial widths.

* Supported in part by the National Science Foundation and the Office of Naval Research.
† Now at the Agricultural and Mechanical College of Texas.
[1] See preceding abstract.

**P11. Total Proton Reaction Cross Section for Copper at 9 Mev.*** RICHARD F. CARLSON, ROBERT M. EISBERG,† RICHARD H. STOKES,‡ AND THOMAS H. SHORT, *The University of Minnesota.*—A beam attenuation technique has been used to measure the reaction cross section of copper at an average proton energy of 9 Mev. The 10-Mev proton beam from the University of Minnesota linear accelerator was passed through three proportional counters and a 1.2-Mev thick copper attenuator into a stopping counter. The cross section was determined by measuring the anticoincidence rate between the stopping counter and the three proportional counters in coincidence. The result, $980\pm75$ mb, agrees with experiments that measure the reaction cross section in a direct manner[1]; on the other hand, the method of summing partial cross sections has yielded conflicting results.[2] Our measurement implies that either the absorbing part of the optical potential is concentrated at the nuclear surface or the imaginary part of the potential is extended beyond the real part.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at the University of California, Santa Barbara, California.
‡ Now at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
[1] For example, G. W. Greenlees and O. N. Jarvis, "Proceedings of the Kingston Conference," 1960 (unpublished).
[2] For example, G. A. Jones and J. P. Schiffen, Bull. Am. Phys. Soc. 6, 273 (1961), and V. Meyer and N. M. Hintz, Phys. Rev. Letters 5, 207 (1960).

**P12. Nuclear Level Density Parameters and the Statistical Decay of the Compound Nucleus.*** NORTON M. HINTZ AND VERENA MEYER,† *University of Minnesota.*—The energy and angular distribution of 9.89-Mev protons inelastically scattered from a number of nuclei in the Ti-Zn region have been measured using a CsI detector. The data have been analyzed in the usual way to obtain nuclear temperatures. In addition, the ratio of the cross sections $(p,p')$ to $(p,\alpha)$ and $(p,n)$ have been used to determine the energy gap parameter $\Delta$ in the nuclear level density formula, $\rho(E)=\exp[(E-\Delta)/T]$. The resulting values of $T$ and $\Delta$ are compared with those obtained from direct level counting in high resolution $(p,p')$ and $(d,p)$ experiments by Buechner *et al.* and are found to be generally in very good agreement. This provides direct verification of the statistical theory of nuclear reactions which states that the decay of the compound nucleus is governed only by phase space and barrier penetration factors. Finally, it is shown how an analysis of the *fluctuations* in the evaporation spectra can be used to determine the absolute value of the nuclear level density and thus, the energy gap parameter $\Delta$.

* Supported in part by the U. S. Atomic Energy Commission.
† Present address: Physikalisches Institut, Universitat, Zurich.

**P13. High Resolution Study of the $Bi^{209}(d,p)Bi^{210}$ Reaction.*** J. R. ERSKINE, W. W. BUECHNER, AND H. A. ENGE, *MIT.*—The $Bi^{209}(d,p)Bi^{210}$ reaction has been studied with 12-kev resolution using a multiple-gap magnetic spectrograph. The ground-state $Q$ value was measured to be $2.362\pm0.010$ Mev. The $Q$ values and angular distributions of more than 38 energy levels have been obtained. The 7.5-Mev bombarding energy which was used is much less than the size of the Coulomb barrier. The angular distributions are all peaked in the backwards direction with maxima at 180 degrees, as would be expected when the conditions for Oppenheimer-Phillips stripping are well met. The first 10 groups are well separated from the remainder, and on the assumption that their intensities follow the $(2J+1)$ rule they appear to arise from the expected $h_{9/2}g_{9/2}$ configuration. The best fit for the order of the spins starting with the ground state is $J=1$, 0, 9, 2, 3, 5, 8, 4, 6, and 7. This order corresponds reasonably well with predictions which have been made using a zero-range interaction. The relative intensities of the different configurations show a dependence on the $l$ value of the orbit into which the neutron is captured. This may furnish a new spectroscopic tool, since it may be possible to calculate this dependence on $l$.

* This work has been supported in part with funds provided by the U. S. Atomic Energy Commission, the Office of Naval Research, and the U.S. Air Force Office of Scientific Research.

SATURDAY MORNING AT 9:30 a.m.

Rosenwald 2

(S. S. HANNA presiding)

## *Apparatus of Nuclear Physics and Mössbauer Effect*

**Q1. High-Current Constant-Potential Electron Accelerator.** M. R. CLELAND, *Radiation Dynamics, Inc.*—A high-current electron accelerator, the Dynamitron,[1,2] has been developed using a new cascaded rectifier system. The cascaded rectifiers are driven in parallel through coupling capacitors whose electrodes are the halves of split corona rings and hemicylinders coaxial with these rings, and whose dielectric is the gas ($SF_6$) used to provide dc insulation. The driving voltage is 300 kc rf at voltages up to 300 kv peak-to-peak, obtained from a parallel resonant circuit whose capacitance elements are formed by the hemicylindrical driving electrodes and the containing pressure vessel and whose inductance is a toroidal coil having high Q. This resonant circuit is enclosed within the pressure vessel so that it is also insulated by the $SF_6$. The circuitry is powered by a vacuum tube oscillator using induction heating techniques and components. Accelerators of this type have been made to yield 10 ma of electron beam current at voltages up to 1.5 Mev, and are now in use in industrial and research applications. One of these, used as an x-ray generator by allowing the electron beam to strike a water-cooled tungsten target, has provided an x-ray flux of $1.8\times10^4$ r/hr in the forward direction at a distance of 1.0 m from the target and at an energy of 1.0 Mev.

[1] M. R. Cleland and K. H. Morganstern, IRE Trans. Industrial Electrons IE-7, 36 (1960).
[2] M. R. Cleland, U. S. Patent 2,875, 394.

**Q2. Duo-Plasmatron with Variable Parameters.** K. EKLUND, *Radiation Dynamics, Inc.*—In order to study the characteristics of a duo-plasmatron ion source, a configuration was chosen that would allow easy variation of mechanical, as well as electrical, operational parameters. By use of a stacked-cylinder-and-plane construction, obtained by mounting the the source electrodes on plates separated by glass insulating spacers, the shapes and relative positions of the electrodes could be changed without changing the basic source elements. As a byproduct of this construction, the arc conditions and magnetic plasma confinement are made visible allowing qualitative source performance to be monitored. Output yields of 20 ma have been obtained for a source having a 0.01-in. diam aperture, with arc, filament and magnets drawing 170, 120, and 35 w, respectively. Output currents can be continuously varied by a factor of more than 30 by changing arc and magnet currents. Axial alignment is also a critical factor since, with an anode and intermediate electrode aperture diameters of 0.01 in. and 0.107 in. respectively, an axial displacement from optimum alignment of 0.020 in. reduced the yield by a factor of 2 and one of 0.050 in. reduced the yield by a factor of 10. The effects of varying other parameters will be described.

**Q3. A Small Angle Scattering System for Gas Targets.*** T. H. JEONG AND L. H. JOHNSTON, *University of Minnesota.*—A scattering chamber, pressure indicator, and pressure regulator have been built for scattering experiments with gases over an angular range of 2° to 122°. The chamber has two telescopes covering ±2° to ±27° and 25° to 122°, respectively. Other features include traveling anti-scatterers, a sextant sensitive to $10^{-4}$ radians for setting the small angle telescope, and a small internal Faraday cup. The pressure indicator is a balance with a large piston on one arm and variable weights on the other. One side of the piston is exposed to the pressure of the chamber, the other side, along with the fulcrum, is under vacuum. This indicator can measure pressures down to ¼ mm of mercury to ±0.5%. During "continuous flow," the pressure is regulated by the exit valve, operated by a membrane. One side of this membrane is open to the chamber while the other side to a reference pressure. The regulator acts in such a way as to maintain the number of scattering centers per unit volume constant during changes in temperature. Preliminary data on the eleastic scattering of 10-Mev protons on argon will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

**Q4. Effect of Delta Rays on the Response of Activated Inorganic Scintillators to Heavy Ions.** A. MEYER AND R. B. MURRAY, *Oak Ridge National Laboratory.**—A semiempirical model describing the scintillation process in activated alkali iodides has recently been proposed.[1] For a given activator concentration this model treats scintillation efficiency as a function of only the $dE/dx$ of the incident particle. Experiments with heavy ions[2] indicate that scintillation efficiency is not a function of $dE/dx$ alone, but is instead composed of a series of discrete functions, one for each incident particle. This paper describes an extension of the previous model to consider the effect of delta rays produced by the primary particle. These energetic secondary electrons escape from the primary ionization column where the luminescent centers are saturared, and produce light with a high efficiency. This effect is most pronounced at high velocities of the incident particle, hence low $dE/dx$. An approximate calculation of these effects predicts the discrete nature of the scintillation efficiency for various particles, and is in qualitative agreement with experiment.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
[1] R. B. Murray and A. Meyer, Phys. Rev. 122, 185 (1961).
[2] E. Newman and F. E. Steigert, Phys. Rev. 118, 1575 (1960).

**Q5. Studies of the Scintillation Process in CsI(Tl).** R. GWIN AND R. B. MURRAY, *Oak Ridge National Laboratory.**—This paper reports a series of experiments on the scintillation response of CsI(Tl) crystals to gammas, protons, and alphas of known energy. This study is intended to investigate some specific predictions of a proposed model of the scintillation process (see accompanying abstract). Measurements of pulse height per unit energy have been performed in detail for these particles on three crystals whose Tl content varies from 0.0041 to 0.18 mole percent. Gamma-ray experiments in the energy range 10 kev to 2.7 Mev demonstrates a distinctly nonproportional pulse height versus energy relation for each crystal, and the shape of this curve is essentially the same for all crystals. Thus the nonproportional response to gammas is little affected by large changes in Tl concentration, in qualitative agreement with the theory. Analysis of these data yields the pulse height per unit energy for *electrons* which is found to be an energy-dependent function with a maximum near 20 kev. The pulse height per unit energy for protons is found to increase monotonically from 0.2 to 5 Mev. Effects dependent on pulse clipping time will be discussed.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

**Q6. Mössbauer Effect for $Fe^{57}$ in Beryllium.*** J. P. SCHIFFER, J. HEBERLE, AND P. PARKS, *Argonne National Laboratory.*—In order to study the behavior of impurities in a lattice, a $Co^{57}$ source was electroplated onto a Be disk. The activity was

diffused into the Be by heating. The resonant absorption of 14-kev gamma rays from this source was studied as a function of velocity. The gamma-ray line was unsplit but broadened to about 0.33 mm/sec. The Mössbauer $f$ for the source is 0.60 $\pm$0.04 at 80°K. The temperature shift between 80° and 290°K was found to be $0.113\pm0.005$ mm/sec or $5.5\times10^{-8}$ ev. Using the Debye model as a simple approximation, one can calculate an effective Debye temperature for the Fe atoms in Be from these data in two ways. From the $f$ value one obtains $150\pm10$°K for $\theta_D$ and from the temperature shift one gets $440\pm40$°K. An absorber was prepared by plating enriched $Fe^{57}$ onto a Be disk and heating it; the absorption line was broadened asymmetrically probably because of the higher concentration of Fe atoms.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**Q7. Measurement of the Internal Magnetic Field at $Fe^{57}$ Nuclei in FeSi Alloys.** M. B. STEARNS, *Ford Motor Company.*—The internal field in FeSi alloys varying in content from 0 to 25.5 atomic percent Si have been measured by observing the hyperfine splitting in a "Mössbauer type" experiment. $Co^{57}$ diffused into stainless steel was used as the source and the FeSi alloys either in foil or powder form were used as the absorbers. The source was moved. The internal field at the $Fe^{57}$ nuclei was observed to decrease linearly with increasing concentration of the Si atoms for the disordered alloys (to about 13 $a/o$ Si). Above this, for the ordered alloys, the various hyperfine components tend to broaden slightly but correspond to a more or less fixed field. The curves of the hyperfine structure give evidence that mainly two distinct fields are present. For the 25 $a/o$ Si we indeed get two distinct fields, one corresponding to an internal field of $H_D\sim0.95\ H_{Fe}$ for the Fe atoms surrounded by 8 Fe atoms and another corresponding to a field of $H_A\sim0.6\ H_{Fe}$ for the Fe atoms surrounded by four Si atoms and four Fe atoms. The form of the linear decrease in the disordered region is such that considering this data in conjunction with magnetization measurements[1,2] and paramagnetic susceptibility measurements[3] of these alloys it can be concluded that for this system the internal field at the Fe nuclei is not simply proportional to the moment on the Fe atom.

[1] D. Parsons, W. Sucksmith, and J. E. Thompson, Phil. Mag. 3, 1174 (1959).
[2] M. Fallot, Ann. Phys. 6, 305 (1936).
[3] S. Arajs and D. S. Miller, J. Appl. Phys. 31, 986 (1960).

**Q8. Nuclear Magnetic Resonance of $Fe^{57}$ in Dilute Ferromagnetic Solid Solutions of Iron.** J. I. BUDNICK, *IBM Watson Laboratory,* AND R. C. LAFORCE AND G. F. DAY, *University of California, Berkeley, California.*—The nuclear magnetic resonance absorption of $Fe^{57}$ has been studied in solid solutions of iron containing cobalt and nickel in concentrations up to two percent. In these systems a discrete satellite resonance is observed on the high frequency side of a broadened main resonance line. The satellite may be explained in terms of a resonance of $Fe^{57}$ nuclei situated in some near neighbor shell about the impurity. Resonances of $Fe^{57}$ nuclei at greater distances from the impurity may contribute to the breadth of the main line[1] which at 4.2°K is approximately 6 to 8 times the linewidth in a pure iron sample. The center frequency of the satellite is approximately 0.65 mc higher than that of the main line for the 1% Co in Fe sample at 4.2°K.

[1] Y. Koi, A. Tsujimura, T. Hihara, and T. Kushida, J. Phys. Soc. Japan 16, 1040 (1961).

**Q9. Recoil-Free Nuclear Resonance Gamma Scattering in Total Reflection from $Fe^{57}$ Mirror.** E. C. CAMPBELL AND S. BERNSTEIN, *Oak Ridge National Laboratory.*—Measurements are reported on the reflectivity $R$ of an $Fe^{57}$ mirror for the 14.4-kev gamma rays from a $Co^{57}$ source (unsplit line) as a function of source velocity $v$ and (small) glancing angle $\theta$. The technique of the Mössbauer effect, combined with that of total reflection, permits the study of coherent nuclear resonant gamma scattering through the region of nuclear anomalous dispersion by Doppler-shifting the source frequency. The observed fine structure depends on the chemical and magnetic environment of those $Fe^{57}$ nuclei which lie in a very thin surface film of thickness equal to the gamma penetration depth. According to theory $R(v,\theta)$ depends on the complex forward scattering amplitude $f(v)=f_e+f_n(v)$ with superposed contributions from electronic and nuclear scattering. The function $f_n(v)$ is given by a multi-level Breit-Wigner expression. Numerical computation of $R(v,\theta)$ is in progress. From a partially oxidized mirror of 89.9% enriched $Fe^{57}$ (300 A thick) evaporated on a glass optical flat we observe large (40%) changes in $R(v)$. The most prominent feature at $\theta=1.7\times10^{-3}$ is a double valley with minima at 0.09 and $-0.01$ cm/sec. For $\theta=3.1\times10^{-3}$, $R(v)$ exhibits several minima as well as a peak at 0.6 cm/sec. The observed scattering resonance pattern is attributed to FeO and $Fe_2O_3$.

**Q10. $Fe^{57}$ Mössbauer Effect in Iron Rare-Earth Cubic Laves Phase Compounds.** G. K. WERTHEIM AND J. H. WERNICK, *Bell Telephone Laboratories, Inc.*—The magnetic properties of iron in cubic Laves phase compounds having the $MgCu_2$ structure have been investigated using the $Fe^{57}$ Mössbauer effect. The field at the nucleus was found to be $230\pm5$ koe in all compounds except $CeFe_2$ where two distinct hyperfine structures were resolved. The results indicate that the configuration of the iron atoms is the same in all these compounds and that the contribution to the hyperfine field by the conduction electron polarization is either very small or else dominated by the iron $d$ shell. The more complex behavior in $CeFe_2$ is associated with the transfer of the cerium $4f$ electron to the iron $d$ band. The isomer shift indicates that this electron is not localized on a particular iron atom, while the existence of two distinct hyperfine fields suggests that there may be a spatially periodic spin density fluctuation in the $d$ band.

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SATURDAY AFTERNOON AT 1:30 p.m.

Mandel Hall

(H. H. BARSCHALL presiding)

## *Invited Papers in Nuclear Physics*

**R1. Nuclear Models.** D. R. INGLIS, *Argonne National Laboratory.* (30 min.)

**R2. The Lewis Effect in Nuclear Resonance Yields.** R. G. HERB, *University of Wisconsin.* (30 min.)

**R3. Study of Photo-Nuclear Reactions Using Annihilation Radiation from Fast Positrons.** S. C. FULTZ, *Lawrence Radiation Laboratory.* (30 min.)

**R4. Mirror States in Medium Weight Nuclei.** J. D. ANDERSON, *Lawrence Radiation Laboratory.* (30 min.)

SATURDAY AFTERNOON AT 1:30 p.m.

Breasted Hall, The Oriental Institute

(J. S. KOEHLER presiding)

## *Nuclear and Electron Spin Resonance*

**S1. Experiments Relating to the Concept of Spin Temperature in a Rotating Reference Frame.*** WALTER I. GOLDBURG, *The Pennsylvania State University.*—Nuclear magnetic resonance experiments were performed which further verify Redfield's assumption that, for large rf fields $H_1(\nu)$, a nuclear spin system is properly described by a spin temperature in a reference frame rotating about the Zeeman field with frequency $\nu$. The experimental technique was that described in reference 1 except that the saturating field was applied for a time short compared to $T_1$ (but long compared to $T_2$). As with similar experiments recently performed by Slichter and Holton,[2] the interpretation of our results does not require any assumption about the spin-lattice relaxation mechanism. Measurements were made on the $Na^{23}$ spins in NaCl and the $F^{19}$ spins in $CaF_2$. In NaCl, agreement between theory and experiment was obtained if the internal energy of the spin system is assumed to arise from magnetic dipole interactions alone. Also studied was the rate of approach of the spin systems to thermal equilibrium in the rotating frame.

* This work was supported by grants from the National Science Foundation and the U. S. Army Research Office (Durham).
[1] Walter I. Goldburg, Phys. Rev. 122, 831 (1961).
[2] C. P. Slichter and William C. Holton, Phys. Rev. 122, 1701 (1961).

**S2. Nuclear Magnetic Resonance of $Tc^{99}$ and $V^{51}$ in Tc-V Alloys.*** D. O. VAN OSTENBURG, H. TRAPP, AND D. J. LAM, *Argonne National Laboratory.*—The nuclear magnetic resonance of $Tc^{99}$ has been observed for the first time in the solid state in 50–50 at.% CsCl-type TcV and bcc $TcV_3$ alloys and its properties studied as a function of field and temperature. Failure to observe the signal in pure hexagonal technetium is due to the interaction of its quadrupole moment with the environment. The $Tc^{99}$ resonance curve in TcV is Lorentzian with a width (measured between extreme slopes of the absorption line) $\delta H=(11.6\pm1)$ oe and is independent of field (3 to 15 koe) within experimental error. The frequency shift relative to a solution of $CsTcO_4$ is positive and independent of field with a value of $0.64\pm0.03\%$. Observation of $V^{51}$ in the same alloy gives a Gaussian curve with a field independent width of $11.3\pm1$ oe and a positive field independent frequency shift relative to vanadium dissolved in $HNO_3$ of $0.57\pm0.03\%$. Calculations show that dipolar broadening cannot account for the entire linewidths and that in view of the different curve shapes, several broadening mechanisms are operative. Probable causes for the linewidths and shapes in these alloys will be discussed.

* Supported by the U. S. Atomic Energy Commission.

**S3. Pulsed NMR in Single Crystals of Ice.** D. E. BARNAAL AND I. J. LOWE,* *University of Minnesota.*—Free induction decay (f.i.d.) shapes and spin lattice relaxation times have been determined for a number of single crystals of ice from −4°C to −140°C. The f.i.d. shapes display 60° symmetry for rotation of the crystal about its $c$ axis and 180° symmetry for rotation of the crystal perpendicular to its $c$ axis (axis of rotation perpendicular to the magnetic field). Below −25°C the f.i.d. shapes were essentially independent of temperature and displayed a beat pattern which did not cross the axis at equally spaced intervals. Above −25°C the f.i.d.'s lengthened with increasing temperature and the beat pattern slowly disappeared. $T_1$ was found to have an anisotropy of less than 2% for rotations about the $c$ axis at temperatures above −35°C. At −50°C a 6% variation in $T_1$ with 60° symmetry was observed. Between −4 and −35°C, $T_1$'s of all samples are described by an activation energy of 13.9 kcal/mole, agreeing quite well with dielectric relaxation measurements.[1] Between −35° and −140°C a lower activation energy was found which varied from sample to sample. All samples had $T_1$'s of 0.75 sec at −5°C and our longest $T_1$ at −105°C was $10^4$ sec. With the $c$ axis along the magnetic field, $T_1$ was larger by 10% at −10°C, and 20% at −40°C than the $T_1$'s for the $c$ axis perpendicular to the magnetic field. Possible interpretations of f.i.d. shapes and $T_1$ dependence will be given in terms of lattice structure and lattice motions.

* Alfred P. Sloan Fellow.
[1] H. Granicher, Proc. Roy. Soc. (London) A247, 453 (1957).

**S4. An Analysis of the Saturation of the EPR Absorption of the *F* Center.*** GORDON A. NOBLE, *Physics Division, Armour Research Foundation.*—The magnetic resonance of the $F$ center was one of the first inhomogeneously broadened EPR lines to be studied. The saturation properties were interpreted by Portis.[1] More recent work using field modulation rather than power modulation has shown a departure from this relationship between saturation factor and applied power. Portis's interpretation assumed that the multiplets are narrow and Lorentzian in shape. Departures from this behavior have been observed in the $Cl_2^-$ center by Castner[2] where the multiplet width is comparable to the linewidth. Experiments show that the multiplets composing the $F$-center line are narrow compared to the linewidth. Experiments on the $F$ center have shown that the multiplets are narrow compared to the linewidth.[3] The departure at high powers can be caused by the detailed shape of the tail of the multiplet. A fair fit to the data can be made using a multiplet shape whichi s intermediate between a Gaussian and a Lorentzian.

* This work was supported by the U. S. Atomic Energy Commission.
[1] A. M. Portis, Phys. Rev. 91, 1071 (1953).
[2] T. G. Castner, Jr., Phys. Rev. 115, 1506 (1959).
[3] G. A. Noble, Bull. Am. Phys. Soc. 5, 327 (1959).

**S5. Paramagnetic Resonance of Trivalent $Pm^{147}$ in Lanthanum Ethyl Sulfate.*** H. J. STAPLETON,† C. D. JEFFRIES, AND D. A. SHIRLEY, *University of California, Berkeley.*—Paramagnetic resonance absorption at 3-cm wavelengths is observed for trivalent $Pm^{147}$ in a single crystal of lanthanum ethyl sulfate at 4.2°K. The observed spectra correspond to eight hfs transitions of a system described by the spin Hamiltonian

$$\mathcal{H}=g_{\|}\beta H_z S_z+AI_zS_z+\Delta_xS_x+\Delta_yS_y,$$

with $S=\frac{1}{2}$, $I=\frac{7}{2}$, $|g_{\|}|=0.432\pm0.004$, and $|A|/h=496.6\pm4$ Mc/sec. The value of $\Delta=(\Delta_x^2+\Delta_y^2)^{\frac{1}{2}}$ is not directly measured in this experiment but is known from nuclear alignment to be $\Delta/k=0.02\pm0.01$°K. The line shapes exhibit an asymmetry typical of non-Kramer's doublets and become unobservable in a few days presumably due to broadening from radiation damage to the crystal. The experimental value of $g_{\|}$ is found to be in reasonable agreement with that predicted from crystal field theory. Effects from higher $J$ level admixtures are taken

into account in estimating the nuclear magnetic moment value $|\mu(Pm^{147})| = 3.0 \pm 0.3$ nm.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Present address: University of Illinois.

**S6. Paramagnetic Resonance of $Co^{2+}$ and $V^{3+}$ in ZnO.** T. L. ESTLE AND M. DE WIT, *Texas Instruments Incorporated.*—EPR spectra attributed to $V^{2+}$ and $Co^{2+}$ as substitutional impurities in ZnO have been observed. Cobalt shows an anisotropic, partially resolved, 8-line h.f. spectrum at 1.3°K and 9149 Mc/sec. The spectrum is described by a spin Hamiltonian with $S = \frac{1}{2}$, a large zero field splitting $2D$, and $g_{\parallel} = 2.243 \pm 0.001$, $g_{\perp} = 2.2791 \pm 0.0002$, $A = (16.11 \pm 0.05) \times 10^{-4}$ cm$^{-1}$, $B = (3.00 \pm 0.03) \times 10^{-4}$ cm$^{-1}$. The intensities at 1.3° and 4.2°K give $2D = 5.5 \pm 0.3$ cm$^{-1}$. A weak spectrum identified from its hyperfine structure as resulting from pairs of interacting $Co^{2+}$ ions was also observed. The intensity is greatest at 1.3°K indicating either ferromagnetic or weak antiferromagnetic coupling. The anisotropic vanadium spectrum observed at 1.3°K and 9138.6 Mc/sec shows an eight-line hyperfine structure and in addition strong satellites when the external field is not parallel or perpendicular to the $c$ axis. The results can be explained by a spin Hamiltonian with $S = \frac{1}{2}$, $D \simeq h\nu$, $g_{\parallel} = 1.977 \pm 0.001$, $g_{\perp} \simeq 2$ and a hyperfine splitting of about 50 gauss. Donors, which were present at a concentration of about $2 \times 10^{17}$ cm$^{-3}$ in the crystal containing the vanadium, gave a narrow resonance at $g = 1.96$.

**S7. Paramagnetic Resonance of $Fe^{3+}$ in Guanidine Aluminum Sulfate Hexahydrate.** D. STIRPE, E. G. BROCK, AND E. I. HORMATS, *General Dynamics/Electronics, Rochester, New York.*—The paramagnetic spectrum of $Fe^{3+}$ substituted for $Al^{3+}$ in guanidine aluminum sulfate hexahydrate, $C(NH_2)_3Al(SO_4)_2 \cdot 6H_2O$, was measured at $X$-band and $K$-band frequencies at room temperature and 77°K. The measurements were made on crystals containing nominally 1 atomic percent and 0.1 atomic percent iron. Spectra were observed with the magnetic field parallel to the $c$ axis, which is also the axis of distortion of the octahedra formed by the water molecules. The iron enters substitutionally into two nonequivalent sites, site 2 having twice the population of site 1, and two sets of spectra with an intensity ratio of approximately 2:1 were observed. Exact solutions to the Hamiltonian for a spin $\frac{5}{2}$ ion in a crystalline field of nearly octahedral symmetry were obtained for the special case where the external field is parallel to the $c$ axis. The crystalline field parameters which appear in the Hamiltonian were determined by fitting the experimental data to the exact solutions. In practically all cases the fit was better than 2%. Though there was no experimental evidence to fix the sign of $D$ relative to $a$ and $F$, the fitting procedure gave $D$ negative and $a$ and $F$ positive. For room temperature, and type 2 sites, the parameters in the spin Hamiltonian were calculated as, $g = 2.003$, $D = -0.17601$ cm$^{-1}$, $a = 0.020595$ cm$^{-1}$, $F = 0.10047$ cm$^{-1}$. For type 1 sites at room temperature, $g = 2.003$, $D = -0.18508$ cm$^{-1}$, $a = 0.021966$ cm$^{-1}$, and $F = 0.10530$ cm$^{-1}$. At 77°K for type 2 sites, $g = 2.003$, $D = -0.18902$ cm$^{-1}$, $a = 0.053963$ cm$^{-1}$, $F = 0.15203$ cm$^{-1}$. Type 1 sites at 77°K gave $g = 2.003$, $D = -0.19506$ cm$^{-1}$, $a = 0.059302$ cm$^{-1}$, and $F = 0.16389$ cm$^{-1}$.

**S8. Paramagnetic Resonance in Triplet Naphthalene at Liquid Helium Temperatures.** A. W. HORNIG, *Baird-Atomic, Inc.*, AND JAMES S. HYDE, *Varian Associates.*—Theoretical calculations[1,2] of the zero-field splitting in triplet naphthalene are in rough agreement with measurements by electron resonance.[3] These measurements, performed in dilute naphthalene-durene single crystals at 77°K, give only the *relative* signs of the splitting constants, whereas theory produces *absolute* signs. We have determined the absolute signs experimentally by intensity measurements at 4.2°K and 1.6°K where Boltzman factors are significant. These measurements indicate that the constants $D$ and $E$ of the spin-Hamiltonian, $\mathcal{H} = g\beta \mathbf{H} \cdot g \cdot \mathbf{S} + DS_z^2 + E(S_x^2 - S_y^2)$ have the following signs: $D > 0$; $E < 0$. This is in agreement with the calculations of Gouterman.[1] We have also made qualitative observations of hyperfine structure and quantitative measurements of triplet decay times at low temperatures. Measurements were made in a cold-finger Dewar of unusual design which will be described.

[1] M. Gouterman, J. Chem. Phys. **30**, 1369 (1959).
[2] R. McWeeny, J. Chem. Phys. **34**, 399, 1065 (1961).
[3] C. A. Hutchison, Jr., and B. W. Mangum, J. Chem. Phys. **34**, 908 (1961).

**S9. Electron Spin Resonance of a γ-Irradiated Single Crystal of Mercaptosuccinic Acid.*** Y. H. HAHN AND H. N. REXROAD, *West Virginia University.*—The electron spin resonance has been studied at room temperature in single crystals of γ-irradiated mercaptosuccinic acid grown from water solution. The spectrum consists of from one to four lines depending upon the orientation in the magnetic field. Observed lines had widths of approximately 8 gauss and splittings as small as 3 gauss would have easily been resolvable with the apparatus used. Measurements were made at two frequencies, 9150 and 16 620 Mc/sec, with the somewhat surprising result that all splittings arise from crystalline electric field effects and none from nuclear hyperfine interactions. The principal values of the $g$ tensor are nearly the same for each of the four paramagnetic species, the averages being 2.056, 2.025, and 2.002. These $g$ factors are almost identical to those found in γ-irradiated $L$-cystine dihydrochloride.[1] It is concluded that all resonances arise from the same free radical which has four different orientations in the crystal. We believe the free radical is either $HOOC(CSH)CH_2COOH$ or $HOOC(HCS)CH_2COOH$ with the latter being the most likely.

* Supported by the National Science Foundation.
[1] Yukio Kurita and Walter Gordy, J. Chem. Phys. **34**, 282 (1961).

**S10. Paramagnetic Resonance in Neutron-Irradiated $DPPH_2$.*** Y. W. KIM AND P. W. FRANCE,† *Wayne State University.*—Polycrystalline samples of 1, 1-diphenyl-2-picrylhydrazine ($DPPH_2$) have been irradiated by beams of thermal neutrons. The electron paramagnetic resonance (EPR) absorption of these samples has been investigated at controlled temperatures. The EPR spectra are centered at $g = 2.003$ and exhibit a partially resolved hyperfine structure consisting of seven lines at room temperature. The two extreme lines in the hyperfine structure can be annealed out at elevated temperatures. The remaining five lines have line spacings close to those of the five hyperfine lines in the resolved EPR spectrum of a 1% molar solution of DPPH in tetrachloroethane. EPR spectra of 1% molar solutions of irradiated $DPPH_2$ in tetrachloroethane appear to be identical with the resolved spectrum of DPPH mentioned above, with respect to $g$ value, line spacing, and intensity ratio of lines. These results suggest that the major part of the resolved EPR spectrum of irradiated $DPPH_2$ may be attributed to a formation of DPPH dispersed in host $DPPH_2$ by the radiation treatment.

* Research supported initially by the University of Michigan Institute of Science and Technology, and currently by the U. S. Atomic Energy Commission.
† National Science Foundation Undergraduate Research Program participant.

SATURDAY AFTERNOON AT 2:00 p.m.

Judd 126

(B. WALDMAN presiding)

## *Invited Paper*

**T1. The MURA 50-Mev F.F.A.G. Electron Accelerator.** W. A. WALLENMEYER, *MURA.*

## *Contributed Papers*

## *The MURA Accelerator*

**T2. Magnetic Measurement Equipment for the MURA 50-Mev Electron Accelerator.*** J. R. MULADY, G. E. BUSH, R. O. HAXBY,† C. H. PRUETT, AND W. A. WALLENMEYER, *Midwestern Universities Research Association.*—The necessity for very accurate magnetic field correction on the 50-Mev electron accelerator led to the development of two magnetic measurement systems. Vertical field measurements were taken using a single rotating search coil, driven by a synchronous motor; which generated a 35 cps sine wave proportional in average value to the magnetic field through its center. This signal was rectified and measured with a five-place digital voltmeter. The voltmeter output, together with azimuthal and radial position information, was fed through a coupler to an IBM card punch. Each card contained all the necessary information about a single point in the magnet. Measurement errors of the vertical field was less than 0.1%. In addition, rotating coils mounted at the small radius end of each magnet block are used to monitor the fields now that the vacuum tank is in place and the machine is in operation. The horizontal component of the field was measured with a coil air driven through 180° and its output was read on a galvanometer type fluxmeter. The coil was located in a horizontal plane by a precision ground glass plate supported by air pressure. Median plane fields were measured within 0.1% of the maximum vertical field at that radius.

* Supported by the U. S. Atomic Energy Commission.
† Purdue University, Lafayette, Indiana.

**T3. Methods of Magnetic Field Correction of the MURA 50-Mev Electron Accelerator.*** C. H. PRUETT, M. M. BERNDT, G. DEL CASTILLO, R. O. HAXBY,† R. A. OTTE, L. KASTURI RANGAN,‡ W. A. WALLENMEYER, AND D. E. YOUNG, *Midwestern Universities Research Association.*—The magnetic fields of the 50-Mev electron accelerator have been corrected for operation of the machine at a one-way operating point chosen as suitable for high intensity beam handling experiments. The corrections are compatible with two-way operation. Measured field data were read out on IBM punch cards and then analyzed with the MURA IBM 704 computer to obtain information concerning necessary corrections. Errors in the vertical field component were very similar in magnets of the same type so that corrections designed for one positive (or negative) magnet could be satisfactorily applied to all positive (or negative) magnets. Corrections of the vertical field consisted of correction coils and shims placed in necessary locations and some tuning of the $k$-tuning coils. Magnets were located in approximate position by physical measurements and in final position by magnetic measurements. Improved magnetic field stability was obtained with major improvements in the main magnet power supplies, the support structure of the magnets, the cooling of the magnets, and the system of monitoring the fields of individual magnets.

* Supported by the U. S. Atomic Energy Commission.
† Purdue University, Lafayette, Indiana.
‡ A & M College of Texas, College Station, Texas.

**T4. Effect of Perturbations in the MURA 50-Mev Electron Accelerator.*** G. PARZEN,† C. H. PRUETT, W. A. WALLENMEYER, D. E. YOUNG, J. ANDERSON, AND P. MORTON, *Midwestern Universities Research Association.*—Perturbations of the magnetic field, due to misalignments and other causes, excite the resonances $\nu_x=3$, $\nu_r=4.5$, and $\nu_r+\nu_z=7$ which lie close to the operating point of the machine. These resonances have been studied on the computer, and tolerances were established on how large the field perturbations may be and on how close the operating point may come to these resonances. The field perturbations have been measured on a mesh around the accelerator, and the results have been analyzed and compared with the established tolerances. The results obtained by the experimental field measurements and by the computer studies will be given.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.

**T5. Operation of the MURA 50-Mev Electron Accelerator.*** D. E. YOUNG, C. D. CURTIS, R. A. OTTE, F. L. PETERSON, C. H. PRUETT, F. E. MILLS, C. A. RADMER, E. M. ROWE, M. F. SHEA, DONALD A. SWENSON, AND W. A. WALLENMEYER, *Midwestern Universities Research Association.*—The 50-Mev electron accelerator was operated in the spring of 1960 when two beams were accelerated simultaneously in opposite directions to an energy of about 27 Mev. Subsequent operation has been at a one-way operating point which was chosen to have large stability limits to allow for high intensity. Electrons have been accelerated at this operating point to an energy of 51 Mev. Measured orbit shapes and betatron oscillation frequencies will be compared with those computed from the measured magnetic field data.

* Supported by the U. S. Atomic Energy Commission.

**T6. Vacuum System for the MURA 50-Mev Electron Accelerator.*** E. L. HOLLAR, G. M. LEE, J. N. MCGRUER,† C. W. OWEN, R. M. ROSEN,‡ AND W. R. WINTER, *Midwestern Universities Research Association* (introduced by B. Waldman).—A welded aluminum vacuum chamber is employed in the MURA 50-Mev electron accelerator. The use of dry fluoroelastomer O rings permits baking at temperatures as high as 150°C in a system which contains a large number of sliding seals. Insulating gaps of Viton-A and Teflon allow the introduction of electromagnetic fields for the acceleration of particles. Fifteen movable probes are provided for the study of the behavior of the beam in the accelerator. Pumping is performed by two getter-ion pumps. Incorporation of an omegatron in the system allows continuous analysis of the gas inside the chamber. Operating pressures of 2 or $3\times10^{-7}$ mm Hg are normally achieved and lead to beam lifetimes sufficiently long to permit the study of the beam stacking process.

* Supported by the U. S. Atomic Energy Commission.
† University of Pittsburgh, Pittsburgh, Pennsylvania.
‡ Litton Industries, Beverly Hills, California.

**T7. Injection into the MURA 50-Mev Electron Accelerator.*** R. S. CHRISTIAN, C. D. CURTIS, G. M. LEE, F. E. MILLS, F. L. PETERSON, C. A. RADMER, M. F. SHEA, AND DONALD A. SWENSON, *Midwestern Universities Research Association.*—A multiturn injection system capable of filling the MURA accelerator to the space charge limit is now in operation. The source consists of a pulsed, 100-kev emission limited electron gun located in the magnetic guide field within the vacuum tank. Radial and vertical emittances of $\sim 3\times 10^{-3}$ rad cm exist for a sheet beam. This beam is focused and directed parallel to an equilibrium orbit by an electrostatic inflector ($n=1.5$) designed with the aid of the MURA IBM 704 computer. The emittance of the gun is thus matched to a small fraction of the accelerator acceptance. Available mechanisms to accomplish multiturn injection include betatron acceleration away from the inflector septum, shifting of the orbit by a programmed electrostatic bump, rf knock-in, and space charge damping of the betatron oscillations for high beam intensity.

* Supported by the U. S. Atomic Energy Commission.

**T8. Experience with the Radio-Frequency Accelerating Systems on the MURA 50-Mev Electron Accelerator.*** R. H. HILDEN AND E. M. ROWE, *Midwestern Universities Research Association* (introduced by B. Waldman).—The MURA 50-Mev electron accelerator possesses two separate and distinct radio-frequency accelerating systems. The first system can pick up the beam at injection energy and accelerate the beam through transition to the final energy. The second system is used to supply the energy lost by the "stacked" beam through synchrotron radiation. The frequency and voltage programs of both systems are variable allowing a wide range of pickup and stacking energies. These two systems in conjunction with a betatron core provide a very flexible means for the investigation of the radio-frequency acceleration process in the MURA electron accelerator. This paper describes the two radio-frequency systems and gives some results of investigations carried out with their aid.

* Supported by the U. S. Atomic Energy Commission.

**T9. Study of the Beam Stacking Process with Application to the MURA 50-Mev Electron Accelerator.*** DONALD A. SWENSON, *Midwestern Universities Research Association.*—A statistical study has been made of the beam stacking process employed in the MURA 50-Mev electron accelerator. A method was developed for evaluating the effect of this stacking process on any arrangement of particles stacked in the synchrotron phase space. Given this method, and a means of adding the particles which are stacked with each repetition of the stacking process, a wide variety of beam stacking "experiments" may be simulated. The energy dependence of the synchrotron radiation and the effect of the phase displacement rf system, which is used to restore this energy to the stacked beam, is included in the study. The results of this study will be presented in the form of a series of curves, called energy spectra, which give the density of stacked particles per energy interval of the synchrotron phase space available to the stacked beam. An analysis was made of the effect of the phase displacement system on the azimuthal arrangement of the particles in the stacked beam. This information is pertinent to interpretation of the signal induced on an electrostatic pickup electrode during the phase misplacement process.

* Supported by the U. S. Atomic Energy Commission.

**T10 Beam Stacking Experiments with the MURA 50-Mev Electron Accelerator.*** E. M. ROWE, R. H. HILDEN, F. E. MILLS, AND DONALD A. SWENSON, *Midwestern Universities Research Association.*—A series of experiments have been performed in which circulating beams many times larger than the injected beam have been built up in the MURA accelerator through beam stacking. By careful adjustment of the accelerating and phase displacement programs, the energy spread of the stacked beam was minimized. The circulating currents and densities achieved were measured by observing the signal induced on an electrostatic pickup near the stacked beam as the displacement system restored the energy loss due to synchrotron radiation. The results will be compared with those predicted by theory.

* Supported by the U. S. Atomic Energy Commission.

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## SATURDAY AFTERNOON AT 1:30 p.m.

Social Sciences 122

(F. J. BLATT presiding)

### *Invited Papers*

**U1. Properties of $He^3$ at Low Temperatures.** A. C. ANDERSON, *University of Illinois.* (30 min.)

**U2. Exchange and Correlation in Crystals and Molecules.** J. C. PHILLIPS, *University of Chicago.* (30 min.)

### *Solid-State Theory*

**U3. Influence of Spin-Orbit Interaction on the Transport Properties of Nickel Alloys.** L. BERGER,* *Carnegie Institute of Technology.*—The influence of spin-orbit interaction on the impurity or lattice scattering of conduction electrons in ferromagnetic alloys is discussed. Assuming that two of the five branches of the 3*d* band intersect, it has been found that when this intersection lies at the Fermi level, remarkable features appear in the transport properties. The "ferromagnetic anisotropy of resistivity" $\Delta\rho/\rho_0$ (often called magnetoresistance effect) shows a strong maximum and the "extraordinary Hall conductivity" $\gamma_H$, changes sign. Smit, in his experiments[1] with Ni-Fe and Ni-Co alloys, has reported such a behavior for an electron concentration of 27.7 el/at.

* Supported by the Fonds National Suisse de la Recherche Scientifique.

[1] J. Smit, thesis (Leiden, 1956).

**U4. Dense Electron Gas with a Positive Source.*** ARTHUR J. LAYZER, *Institute of Mathematical Sciences.*—We have considered the application of the perturbative solution of the Schwinger equation for the one-particle Green's function to the ideal problem of a dense infinite electron gas with neutralizing uniform positive background and with a static "source"

consisting of a positive point charge. The densities appropriate to the perturbation expansion are so high as to limit the quantitative applicability of the model to very dense metals or dense degenerate astronomical systems such as white dwarfs. Lowest order expressions for the charge density of the ground state and for the (non-Hermitian) effective Hamiltonian of the single-particle excitation spectrum have been derived using some results of Dubois for the source-free system. The theory predicts the disappearance of the discrete spectrum, presumably of hole type, for densities beyond a certain limiting value, $n \simeq Z^6 a_0^{-3}$, where $Z$ is the atomic number of the source and $a_0$ is the Bohr radius. This result is connected with the fact that at high densities an electron feels a shielded Coulomb potential with a range inversely proportional to the classical plasma frequency. Therefore, if the density is too high, the range will be insufficient to produce binding.

* Supported by the U. S. Atomic Energy Commission.

**U5. Interaction of Crystalline Modes with Deep, Two-Level Electron Traps.** T. N. CASSELMAN AND J. J. MARKHAM,* *Physics Division, Armour Research Foundation.*—The effect of a defect on the broadening of the absorption line of an electron in a two-level, deep trap is explored using as a model, the linear monatomic chain with an isotopic impurity. The changes in the eigenvectors associated with the modes are calculated for a mass defect ratio of $\frac{1}{2}$, 1, 2. Similar changes have been reported on different models by McCombie and co-workers.[1] Hence, the effect is of a very fundamental nature. Using these eigenvalues, the Huang-Rhys factors[2] were obtained. Comparison is made of these factors for all the crystalline modes to the factor for the local mode.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] McCombie, Matthew, and Murray, International Conference on Chemical Physics of Nonmetallic Crystals, Evanston, Illinois (1961).
[2] J. J. Markham, Revs. Modern Phys. 31, 956 (1959).

**U6. Transmission of Bloch Waves through Crystal Interfaces.** P. J. PRICE, *IBM Research.*—For an ordered interface, transmission and reflection of electrons should be determined by the "matching coefficients" of linear relations between the wave amplitudes on the two sides; but these coefficients will depend on the interface region as well as on the electron energy functions for each crystal. As a simple model to represent this situation, the author used the Koster-Slater equations with the energy constants beyond nearest-neighbor taken to be zero (and so with a sinusoidal energy function in each crystal) and with a single additional energy constant connecting neighboring Wannier functions on each side of the interface. The matching coefficients thereby obtained, for "allowed" or "forbidden" Bloch waves on either side, generalize the corresponding results for free electrons and a potential step. The governing parameter is $E_{AA}E_{BB}/E_{AB}^2$, where the $E$'s are the nearest-neighbor energy constants and A, B refer to the two crystals. The results may be applied to the theory of epitaxial heterojunctions,[1] and perhaps to the theory of tunneling between metals through an oxide barrier.

[1] R. L. Anderson, IBM J. Research Develop. 4, 283 (1960).

**U7. A Calculation of the Elastic Shear Constants of Beryllium.** B. T. BERNSTEIN, *Union Carbide Research Institute.*—The contributions to the elastic shear constants of beryllium at 0°K were calculated on the basis of an energy band model for this metal proposed by Herring and Hill.[1] The results were compared with those obtained assuming nearly-free-electron and free-electron behavior for the valence electrons. It was found that the valence electron contribution was very sensitive to the shape of the energy bands, the nearly-free-electron and free-electron calculations greatly overemphasizing the valence electron contributions as compared to the calculations based on the work of Herring and Hill. On the basis of the model proposed by Herring and Hill the elastic shear constants of beryllium, like the alkali metals, are predominantly determined by the electrostatic energy of the ion-cores.

[1] C. Herring and A. G. Hill, Phys. Rev. 58, 132 (1940).

**U8. Exponential Coupling Theory of Fused Salts.** J. L. KATZ, *Atomics International and The University of Chicago,* AND EMMANUEL MEERON, *Atomics International.*—A modification of the indirect exponential coupling method[2] is applied to hard core Coulombic systems (e.g., fused salts and electrolytes), resulting in an integral equation for the pair distribution function, exact through the first power in the coupling parameter:

$$g(12) = \exp[-\beta U^*(12)]\Big\{\exp[-\beta U^\dagger(12)] + \rho \sum_j X_j \int_v f^\dagger(1j)\exp[-\beta U^*(1j)][g(2j)-1]d\mathbf{r}_j\Big\}.$$

Here $g(12)$ is the pair distribution function, $U^*(12)$ is the hard core interaction, $U^\dagger(12)$ the Coulomb interaction, $\rho$ the density, $f^\dagger(1j) = \exp[-\beta U^\dagger(1j)]-1$, and $X_j$ the mole fraction of species $j$. This equation is solved numerically for fused salts, and the results compared with experimental data such as x-ray and neutron scattering intensities and isothermal compressibilities calculated from $g(12)$. The new approximation should be much better than the Debye-Hückel or Kirkwood coupling treatments because we couple the well-behaved $f$ bonds rather than the potentials which assume very large values at small interparticle separations.

[1] E. Meeron (to be published).

**U9. Some Remarks on Correlations in Classical Order-Disorder Phenomena.** F. H. STILLINGER, JR., *Bell Telephone Laboratories.*—By means of a spin-magnitude variation parameter, an equation is derived for spin-pair correlation functions in classical lattice theory. It is assumed that no external field acts on the spin assembly, but the spins may interact through a scalar pair potential of arbitrary range. Spin-triplet correlation functions occurring in the theory, as well as all higher odd order correlation functions, may be reduced exactly to linear combinations of lower order correlation functions. Spin-quadruplet functions, also required for rigorous determination of pair correlation, unfortunately have no corresponding reduction, but their character may qualitatively be established. The approximate theory resulting from use of a simple quadruplet closure allows prediction of the critical temperature for ferromagnetic coupling of varying range. Also, spin-pair correlations at large distance are predicted to be isotropic at this critical temperature, when the interaction satisfies a certain second moment condition.

**U10. Vibrational Modes of Disordered Linear Chains.** HERBERT B. ROSENSTOCK AND RICHARD E. MCGILL, *U. S. Naval Research Laboratory.*—It has been shown that the $k$th normal mode of vibration (i.e., the atomic displacement amplitudes associated with the $k$th lowest frequency) of a disordered one-dimensional lattice with nearest-neighbor interaction has precisely $k$-1 nodes. That is, there is exactly one eigensolution with no nodes, one with one node, one with two nodes, ···, and the larger the number of nodes the higher the corresponding frequency. This theorem holds even if masses, force constants and distances between atoms are completely arbitrary and irregular, and *a fortiori* it holds for ordered lattices with any number of atoms per unit cell, for ordered lattices with defects, etc. It thus exhibits a close relationship between, on the one hand, the normal modes of disordered lattices and, on the other hand, the normal modes of ordered monatomic lattices and of vibrating strings (to which its application has been known for a long time). This relationship may appear surprising in view of recent demonstrations of the gross differences exhibited in the distribution of eigenvalues. Numerical

examples will be given an possible extensions to long-range forces and to higher-dimensional crystals will be discussed.

**U11. Relaxation-Time Distribution Functions for a Thermally Activated Process.** J. Ross Macdonald, *Texas Instruments Incorporated.*—Mechanical, magnetic, or dielectric relaxation systems for which the relaxing process is linear in the stimulus amplitude often exhibit a distribution of thermally activated relaxation ties, $\tau=\tau_a \exp(E/kT)$. A spread in $ln\tau$ about its mean may then arise from a distribution of $\ln\tau_a$, from a distribution of the temperature-independent part of the thermal activation energy $E$, or from simultaneously present distributions of both these quantities. For a distribution of $E$ alone, the temperature dependence of the over-all relaxation-time distribution function is restricted, and usual functions such as those of Cole-Cole, Fuoss-Kirkwood, and Davidson-Cole are inconsistent with this restriction. The Gauss-Wiechert-Wagner distribution and a new distribution to be discussed can be made entirely consistent, however, and the temperature dependences of transient and frequency responses are then largely determined. When $\ln\tau_a$ and $E$ have simultaneous independent Gaussian distributions, their variances, $\sigma_a^2$ and $\sigma_E^2$, combine linearly to yield the measurable variance $\sigma^2=\sigma_a^2+(\sigma_E/kT)^2$ of the combined Gaussian distribution in $\ln\tau$. Here, the temperature dependences of $\sigma_a$ and $\sigma_E$ depend on the details of the process considered.

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## Saturday Afternoon at 1:30 p.m.

### Rosenwald 2

### (G. Weinreich presiding)

### *Solid State, General*

**V1. Geometry and Orientation of Zinc Crystals Grown in a Sonic Field.** W. H. Frandsen and B. Langenecker, *Michelson Laboratory* (introduced by Gilbert J. Plain).—The growth of zinc crystals (purity 99.999% and 99.992%) in a sonic field of ~1 watt/cm² was studied at frequencies within the range 100 to 10 000 cps using a modified Czochralski[1] method. Observing the growing crystal just above the surface of the melt, it was found that the peak of the cone drawn up from the melt by the pulling crystal fell to a lower level upon application of the sonic field. Simultaneously a change in the diameter occurred depending on the direction of the pressure gradient of the sound waves. Furthermore, greater uniformity in cross-sectional area and increased optical roughness appeared when the component of the gradient perpendicular to the longitudinal axis was predominant. It has also been observed that there is a kinking of the growing crystal so long as there is a component of the pressure gradient parallel to the glide direction. Pictures will be shown illustrating these effects. Results of orientation determinations using the x-ray diffraction rotating crystal method[2] showed an increase in $\rho$, the angle formed by the longitudinal axis and the normal to the glide plane, due to the application of the sonic field.

[1] J. Czochralski, Z. physik. Chem. **92**, 219 (1917).
[2] E. Schmid and W. Boas, *Plasticity of Crystals* (F. A. Hughes and Company, London, 1950), pp. 37–40.

**V2. Density and Arrangement of Dislocations in Zinc Crystals Grown in a Sonic Field.** B. Langenecker and W. H. Frandsen, *Michelson Laboratory* (introduced by Gilbert J. Plain).—The micro- and x-ray photographs shown in the previous paper[1] concerning the geometry and orientation of zinc crystals (purity 99.999% and 99.992%) grown in a sonic field of ~1 watt/cm² within the frequency range 100 to 10 000 cps, have been utilized for an initial interpretation of the effect of sound on the process of crystallization from the viewpoint of the dislocation theory. The interpretation involves the concept of superimposition of the pressure (or stress) gradient of sound waves onto the strain energy of nucleation[2] and precipitation of vacancy disks.[3] In addition to the photographs, tensile tests were carried out on these specimens. The temperature dependence of the critical shear stress of the crystals grown with and without sonic irradiation has been measured and estimates of the dislocation densities have been evaluated according to Seeger's theory.[4] Comparisons also have been made in the static yield strength of crystals grown with an without sonic irradiation while low-amplitude vibrations of 20 kc/sec were superimposed onto the tensile tests. The latter method offered another means of calculating the dislocation density. Both methods are in agreement.

[1] See Abstract VI, this issue.
[2] U. Dehlinger, *Encyclopedia of Physics*, edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. VII, Chap. 2, p. 212.
[3] C. Elbaum, J. Appl. Phys. **31**, 1413 (1960).
[4] A. Seeger, Z. Naturforsch. **9a**, 758 (1954).

**V3. Cohesion of Intermetallic Compounds.** H. J. Caulfield and D. E. Hudson, *Iowa State University.*—The analog of the Clausius-Clapeyron equation for reactions of the form $A_nB_m(s) \rightleftharpoons nA(v)+mB(s)$ has been applied to the sublimation of intermetallic compounds of the series $Mg_2X$ (X=Si, Ge, Sn, or Pb).[1] The vapor in equilibrium with $Mg_2X$ was studied by the Knudsen effusion method. The effusing species were observed mass spectrometrically. The enthalpy changes $\Delta H_T$ for Mg subliming from $Mg_2X$ at temperature $T$ are listed below in kilocalories per mole of Mg vapor: $Mg_2Ge$, 54.4±1.1 at 875°K; $Mg_2Sn$, 44.0±1.2 at 821°K; $Mg_2Pb$, 33.6±0.6 at 770°K; and $Mg_2Si$, 44.6±1.6 at 862°K. The determination of cohesive energy values from these data and from data in the literature will be discussed and values will be presented.

[1] A more satisfying derivation of the appropriate equation has been perpared for presentation at the Ninth Annual Midwest Solid State Conference at Argonne, Illinois, on October 21, 1961.

**V4. Low-Temperature Thermal Conductivity of Amorphous Solids.** G. K. Chang and R. E. Jones, *IBM Research Center* (introduced by R. A. Connell).—According to Klemens,[1] the very low-temperature conductivity of amorphous dielectrics is due to conduction by longitudinal phonons. The mean free path for these phonons is limited by an intrinsic scattering with a dependence on the wave number of the phonons: $l\sim k^{-2}$, where $k$ is the wave-number vector. Considering the thermal conductivities of five different samples of commercial glass, it was found that in addition to the intrinsic scattering there was a scattering of phonons by internal boundaries. The mean free path due to these boundaries was found to range from about $10^{-2}$ cm to $10^{-3}$ cm, and there is an indication that the smaller mean free paths were associated with a progressive

devitrification of the glass. The intrinsic scattering was found to be less than that found by Klemens[1] from Berman's[2] data on vitreous quartz.

[1] P. G. Klemens, Proc. Roy. Soc. (London) **A208**, 108 (1951).
[2] R. Berman, Proc. Roy. Soc. (London) **A208**, 90 (1951).

**V5. Thickness Independence of $BaTiO_3$ Switching Time.** HENRY L. STADLER, *Ford Motor Scientific Laboratory.*—Preliminary measurements show that the ferroelectric switching time of $BaTiO_3$ single crystals at a given electric field is independent of crystal thickness in the high field region. The switching time at lower fields depends explicitly on the crystal thickness as well as on the electric field.[1,2] The thickness dependence at lower fields has been interpreted as an indication that new, reversed-polarization domains can only be nucleated at the crystal surface.[1] It has also been interpreted as an indication that sidewise domain wall motion is influenced by nonferroelectric layers on the surface of the crystal.[2,3] The thickness independence of switching time at higher fields could indicate (on the first picture) that reversed-polarization domains can nucleate inside the crystal, possibly on crystal imperfections, at the higher fields. On the second picture it would indicate that surface layers do not significantly affect the switching at higher fields. The measurements were made with crystals grown by a modified Remeika method, whose thickness ranged from 0.007 to 0.047 cm. The high-voltage pulses, generated by a mercury relay pulser, were applied to the crystal inside a coaxial cable. The results can be represented in the field range from 3 to 26 kv/cm by $t_s=[0.13\pm0.03$ sec $(\text{v/cm})^{1.4}]E^{-1.4\pm0.1}$, where $t_s$ is the switching time and $E$ is the applied electric field.

[1] W. J. Merz, J. Appl. Phys. **27**, 938 (1956).
[2] R. C. Miller and A. Savage, J. Appl. Phys. **31**, 662 (1960).
[3] M. E. Drougard and R. Landauer, J. Appl. Phys. **30**, 1663 (1959).

**V6. Dielectric Anomaly for Impacted Quartz*** R. A. GRAHAM, *Sandia Corporation* (introduced by W. P. Brooks).—The piezoelectric behavior of X-cut, synthetic, alpha-quartz is observed for transient stress of from 5 to 50 kbars.[1] As first observed by Neilson and Benedick[2] a definite dielectric anomaly exists when the specimen is stressed in the negative $x$ direction. No anomaly is observed for the positive $x$ direction. Below 8 kbars no anomaly is observed. Between 8 and 24 kbars the negative $x$ current waveforms show distortion and evidence of partial electric breakdown in the quartz. Between 25 and 34 kbars disruptive breakdown occurs. Above 34 kbars disruptive breakdown is followed by gross conduction with positive currents being observed for stress greater than about 50 kbars. The fields associated with the piezoelectric behavior are lower than the field for steady state electric breakdown in quartz. It is proposed that the anomaly is triggered by stress induced dislocation motion resulting in liberated electrons which are accelerated into the stressed region of the specimen by the high-negative electric field.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. A. Graham, J. Appl. Phys. **32**, 555 (1961).
[2] F. W. Neilson and W. B. Benedick, Bull. Am. Phys. Soc. **5**, 511 (1960).

**V7. Effect of Isotopic Composition on Infrared Absorption Spectra of Lithium Hydride and Lithium Fluoride** * R. H. MISHO AND D. J. MONTGOMERY, *Michigan State University.*—Infrared absorption spectra of thin films of LiH containing varying proportions of $Li^6$, $Li^7$ and $H^1$, $H^2$ evaporated onto a KBr substrate were obtained in the region 10–28 $\mu$ with a CsBr-prism spectrophotometer. Similar experiments were made in the region 15–36 $\mu$ on films of LiF containing varying proportions of $Li^6$, $Li^7$ and evaporated onto CsBr and polyethylene substrates. For certain compositions spectra were obtained at 300°, 220°, and 120°K. For isotopically-pure materials, the dispersion wavelength at a given temperature varies as the square root of the reduced mass. The introduction of isotopic impurity in LiH changes the shape of the spectrum substantially, and displaces the dispersion wavelength in a complicated manner. In LiF, isotopic impurity changes the shape of the spectrum to a minor degree, and displaces the dispersion wavelength in proportion to the square root of the average reduced mass. At low temperatures, the absorption bands become deeper and narrower, the dispersion wavelength shifting to an extent dependent on the film composition and the substrate. A change in substrate alone produces a measurable shift in dispersion wavelength.

* Supported by the U. S. Air Force Office of Scientific Research and by the U. S. Atomic Energy Commission.

**V8. Magnesium Oxide Radiation Detector (MgO-RAD).** RICHARD G. SAELENS, *U. S. Army Signal Research and Development Laboratory.*—A prototype model of the MgO-RAD has been evaluated at the General Atomic linear accelerator. The device yielded excellent response to five-microsecond pulses of Bremsstrahlung radiation resulting from the stopping of 15-Mev electrons in a platinum target. The dose rate ranged between $10^4$ and $10^6$ r/sec. Essentially, the MgO-RAD consists of a circular 15-mil titanium cylinder $\frac{1}{4}$ in. in diameter and approximately $\frac{1}{2}$ in. long. The inner surface of the titanium cylinder is coated with a thin layer of magnesium oxide (light) plus magnesium oxalate $[MgO+Mg(COO)_2]$. The collector electrode is positioned concentrically inside the titanium envelope. Electrons emitted from the titanium envelope cause a multiplication of electrons through the MgO layer, permitting a high yield for a small detector geometry. Additional experiments are planned at a pulse nuclear reactor, and the results will be reported.

***Post-Deadline Papers, If Any***

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## SATURDAY AFTERNOON AT 1:30 p.m.

## Eckhart 133

## (L. LANGER presiding)

## *Beta and Gamma Spectroscopy II*

**W1. Interpretation of the Beta Decay of $Eu^{152}$.** HARRY DULANEY, C. H. BRADEN, AND L. D. WYLY, *Georgia Institute of Technology.**—The beta-gamma directional correlation and the beta spectral shape for the 1483-kev beta transition in $Eu^{152}$ has previously been interpreted in terms of the "modified $B_{ij}$" approximation. This decay has been reconsidered using the formulae of Kotani[1] without approximation and including the recent determination of the beta-circularly polarized gamma correlation.[2] Computations were made with the aid of a digital computer. The data indicate that the nuclear matrix

element parameter $\zeta_1$ lies between 0.5 and 1. For some suitable sets of matrix element parameters, the quantities $u$ and $x$ are small in qualitative agreement with the "modified $B_{ij}$" approximation. However, other suitable sets of matrix element parameters have $x \approx 0.6$ which is in disagreement with the "modified $B_{ij}$" approximation. The method of analysis used for this decay is generally applicable to first-forbidden beta decays with spin change 1. The results of various types of experiment may be incorporated in the analysis.

* Supported in part by a grant from the National Science Foundation.
[1] T. Kotani, Phys. Rev. 114, 795 (1959).
[2] J. Berthier, R. Lombard, and J. W. Sunier, Compt. rend. 252, 257 (1961).

**W2. Gamma-Gamma Directional Correlation Measurements in $Er^{166}$.*** J. J. Reidy, E. G. Funk, Jr., and J. W. Mihelich, *University of Notre Dame.*—Gamma-gamma directional correlation measurements are being carried out on the gamma-ray cascades in $Er^{166}$ following the electron capture of $Tm^{166}$ (87 days).[1] The purpose of these measurements is to establish the spin and parity of the 1095- and 1543-kev levels, the multipolarities of the transitions from these states, and the multipolarities of the transitions depopulating the gamma-vibrational band. The result of the 1280–185 kev correlation is consistent with a spin sequence 3–4–2 with the 1280-kev transition being dipole (<0.1% quadrupole) assuming the 185-kev transition is pure quadrupole. The result of the 721–822 kev correlation is consistent with a spin sequence 3–2–0 with the 721-kev transition being dipole (<0.1% quadrupole). Results of the other feasible correlations will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] K. P. Jacob, J. W. Mihelich, B. Harmatz, and T. H. Handley, Phys. Rev. 117, 1102 (1960).

**W3. Beta-Gamma Directional Correlations in the Decay of $Tm^{170}$ and $Re^{186}$.** L. D. Wyly, E. T. Patronis, C. H. Braden, and Harry Dulaney, *Georgia Institute of Technology.**—The beta-gamma directional correlations between the 883-kev beta group and the 84-kev gamma in the decay of $Tm^{170}$ and between the 934-kev beta group and the 137-kev gamma in the decay of $Re^{186}$ have been measured. For $Tm^{170}$, the coefficient $A_2$ is found to be in the range $-0.07$ to $-0.10$ over the beta-energy range 520 to 740 kev. For $Re^{186}$, $A_2$ is found to be in the range 0.04 to 0.10 over the beta-energy range 330 to 740 kev. Comparison with previous measurements[1,2] will be made. Interpretation of these decays in terms of restrictions on the nuclear matrix element parameters will be discussed.

* Supported in part by a grant from the National Science Foundation.
[1] G. Bertolini, E. Lazzarini, and M. Mandelli-Bettoni, Nuovo cimento 6, 1106 (1957).
[2] T. B. Novey, M. S. Freedman, F. T. Porter, and F. Wagner, Jr., Phys. Rev. 103, 942 (1956).

**W4. An additional Low-Lying State of $Yb^{173}$.*** R. C. Pilger, Jr., *University of Notre Dame.*—Gamma-ray coincidence measurements have revealed additional transitions of of 223 and 335 kev in the electron-capture decay of $Lu^{173}$ and have established the location of these and of the previously reported 233.8-kev transition[1] in the decay scheme as proceeding to and from an additional excited state at 413.3 kev. Directional correlation and conversion coefficient measurements have established the spin and parity of this state to be 9/2+. Interpretation of this state as part of a rotational band based on the 351.2-kev 7/2+ state indicates a remarkably small inertial parameter, which is, however, in good agreement with the value expected from rotation-particle coupling considerations.[2]

* Work supported in part by the U. S. Atomic Energy Commission.
[1] J. W. Bichard, J. W. Mihelich, and B. Harmatz, Phys. Rev. 116, 720 (1956).
[2] R. C. Pilger, Jr., J. W. Bichard, and J. W. Mihelich, Bull. Am. Phys. Soc. 5, 425 (1960).

**W5. Neutron Deficient Alpha Emitters of Francium.*** Roger D. Griffioen† and Ronald D. MacFarlane, *Lawrence Radiation Laboratory, Berkeley.*—Several new isotopes of francium in the mass region 205–213 have been produced using the various heavy ion beams from the Berkeley heavy ion linear accelerator. Excitation functions for the new alpha groups have been determined for four different compound nucleus systems indicating the masses of these alpha emitters. In several cases the mass assignments were confirmed by the identification of alpha-emitting daughters. Alpha energies have been determined, the half-lives of the isotopes have been measured, and some information on the alpha branching ratios has been obtained. The alpha-decay energy systematics of this region, including these new isotopes, will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Calvin College, Grand Rapids, Michigan.

**W6. Neutron Deficient Alpha Emitters of Erbium.*** Ronald D. MacFarlane and Roger D. Griffioen,† *Lawrence Radiation Laboratory, Berkeley.*—Bombardment of neodymium isotopes with $O^{16}$ ions from the Berkeley heavy ion linear accelerator has resulted in the identification of three new alpha-emitting isotopes of erbium: $Er^{160,3,4}$. They emit alpha particles of 4.78-, 4.68-, and 4.12-Mev energy and decay with half-lives of 10 sec, 35 sec, and 5 min, respectively. Mass assignments were obtained on the basis of excitation function data and substantiated by the identification of the daughters from alpha decay. The alpha-decay properties of these nuclides will be discussed and compared with alpha-decay systematics in this region.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Calvin College, Grand Rapids, Michigan.

**W7. A Computer Program for Analysis of Complex Continuous Beta-Ray Spectra.*** S. B. Burson and R. G. Helmer,† *Argonne National Laboratory.*—In collaboration with W. J. Cody and J. A. Gregory (Argonne Applied Mathematics Division), a two-stage computer program (IBM-704) has been developed for the analysis of complex beta-ray spectra. Only the second stage will be described. The first stage accomplishes standard data reduction. A spectrum comprising as many as 13 components can be analyzed. Each component is presumed to consist of a linear combination of allowed and unique first-forbidden transitions and is represented by three parameters: the slope $m$ of its Fermi plot (related to relative intensity), the end-point energy $\epsilon_0$, and the shape-partition factor $\alpha$. Before the calculation, initial estimates must be made for all parameters of the components assumed to be present. Any of the parameters may be held fixed. Pairs of end points may be related when such energy differences are known. The computation is an iterated least-squares fit to any selected portion or portions of the data. The free, or unfixed, parameters are varied simultaneously in order to minimize the function $\chi^2 = \Sigma_i w_i [N_i - \bar{N}_i(p_j)]^2$, where $N_i$ and $\bar{N}_i(p_j)$ are the experimental and calculated counting rates, and $w_i$ is the weight factor. Criteria for convergence, available options, and some of the known limitations will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Phillips Petroleum Company, Idaho Falls, Idaho.

**W8. Beta Decay of $Es^{254}$.*** P. Day (introduced by M. S. Freedman), S. Vandenbosch, and J. Unick, *Argonne National Laboratory.*—The beta decay of $Es^{254}$ has been studied using gamma-gamma and beta-gamma scintillation coincidence techniques and a double-lens beta-ray spectrometer. *E2* transitions of 103.5±1, 544±5, 583±3, 648±2, and 692±2 kev have been placed in a level scheme of $Fm^{254}$ with levels at

44±3 (0, 2+), 148±3 (0. 4+), 692±2 (2, 2+), and 734±4 (2, 3+) kev. Two beta spectra of 477±4 (72%) and 1127±2 (28%) kev were observed. The observation of the (2, 2+) gamma-vibrational state at 692 kev in $Fm^{254}$ indicates that there is a sharp decrease in the gamma-vibrational energy for 154 neutrons. Gamma-vibrational bands have previously been observed at 1030 kev in $Pu^{238}$ (144 neutrons) and $Cf^{250}$ (152 neutrons). By following the decay of two points on the beta spectrum and the decay of the high-energy gamma rays, a half-life of 39.3±0.2 hr was obtained. During the course of this work transitions of 93±2, 377±3, 386±1, and 427±3 kev were observed from the decay of 20-day $Es^{253}$.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

## SUPPLEMENTARY PROGRAMME

**SP1. Explosive Origin of Energy outside the Milky Way.*** JOSEPH G. BARREDO, *C. S. I. C.*—Considering: (1) It was previously believed that the physicist had to ask nature to pass judgment on his theories but the mathematician only had to assure himself that his theorems followed from his axioms; (2) If this description were accurate mathematics could not attract any intelligent being, as indicated in the 1958 International Mathematical Congress Presidential Address; (3) Only under the discipline of responsibility to the organic whole can the free mind achieve results of scientific value, (4) The concept of observable was mathematically and physically undefined (see Proceedings of the 1959 International Axiomatic Method Symposium, p. 52) and it is the crucial problem of epistomology, specially since Descartes unified algebra and geometry through the naive concept of coordinate. The concept of observable was defined as the explosion of two charges within a trion, i.e., a configuration formed by three charges in a row the one in the middle of different sign than the other two. In this way it is explained: (1) The extragalactic energy (even in double elliptical radio sources) is produced by explosion of cosmons, i.e., trions of cross section $<10^{-64}$ cm$^2$; (2) Collision theories are incorrect not by misusing mathematical concepts but because these concepts are extragalactic and microphysically meaningless.

* To be given at the end of Session K if the Chairman rules that time permits.

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# Proceedings of the American Physical Society

MINUTES OF THE MEETING OF THE SOUTHEASTERN SECTION HELD AT THE UNIVERSITY OF LOUISVILLE, LOUISVILLE, KENTUCKY, MARCH 30, 31, AND APRIL 1, 1961

THE twenty-seventh meeting of the Southeastern Section of the American Physical Society, held at the University of Louisville on March 30, 31, and April 1, 1961, was attended by about 275 physicists from the region. The arrangements at Louisville were made by a committee headed by D. M. Bennett; the program was planned by another committee chaired by Ingram Bloch. The program of 14 invited and 57 contributed papers appears below. Titles of 2 invited lectures and 9 additional papers related to physics teaching are recorded in the *American Journal of Physics*. The dinner address, "A National Science Program," was given by Wallace R. Brode, retired from the National Bureau of Standards. During the meeting the Section chose Florida State University, Tallahassee, Florida, as the site of its 1962 meeting on April 5, 6, and 7. The Section also elected the following as its officers for 1961–1962: Ingram Bloch, Vanderbilt University, *chairman;* Frank Hereford, University of Virginia, *vice-chairman;* Howard Carr, Auburn University, *secretary;* Myron McCay, University of Chattanooga, *treasurer;* and Arthur Snell, Oak Ridge National Laboratory, and Dave Wyly, Georgia Institute of Technology, *executive committeemen*. Joe Fowler, of the Oak Ridge National Laboratory, is the retiring chairman.

HOWARD CARR, *Secretary*
Southeastern Section

## *Nuclear Instrumentation*

### *Invited Paper*

**A1. Mechanism of the Scintillation Process in Alkali Iodides.** R. B. MURRAY, *Oak Ridge National Laboratory.*

### *Contributed Papers*

**A2. A Low Atomic Number Solid-State Radiation Detector.*** H. J. FULLBRIGHT, III, BRUCE L. BLANKS, AND ROBERT H. ROHRER, *Emory University.*—A solid-state gamma and x-radiation detector has been constructed. The detecting element is an anthracene crystal 1.27 cm in diameter and 0.2 cm thick. The crystal is mounted in a Lucite sandwich-type holder, and the electrodes are of water-base Aquadag, a colloidal suspension of carbon. The geometric arrangement of the electrodes is such that surface conduction of the crystal and bulk conduction of the holder are not measured and the true volume photoconductivity of the anthracene is utilized. The entire device is shielded in a manner to prevent the measurement of air ionization. The illumination of the cell is obtained from a 220-kvp x-ray generator and from a small source of $Co^{60}$. The photocurrent is on the order of $4\times10^{-13}$ amp per roentgen, which is in range of the currents obtained with ultraviolet illumination.[1] The wavelength, intensity, and voltage dependence of the current has been examined. A description of the cell and the system is given. A brief summary of the results and possible applications of this type of dosimeter are presented.

* Supported by the U. S. Public Health Service.
[1] J. Kommandeur and W. G. Schneider, J. Chem. Phys. **28**, 582, 590 (1958).

**A3. Effects of Temperature on Photomultiplier Tubes.** D. L. KILBOURN, *Auburn University.*—A number of DuMont 6292 photomultiplier tubes were subjected to various temperatures. Results showed that the output response of the photomultiplier tube was temperature dependent. A summary of the work is presented along with a comparison of results with those of other investigators.

**A4. Resolution, Stability, and Noise in Si Nuclear Particle Detectors.** F. J. WALTER, J. W. T. DABBS, AND L. D. ROBERTS, *Oak Ridge National Laboratory.* In earlier work[1] a theoretical model describing the behavior of semiconductor particle detectors was given which seemed to agree rather well with our experimental results on Ge surface-barrier detectors over a wide range of parameters. More recently, this work has been extended to the use of Si detectors in the temperature range 77–300°K. Several new methods of crystal mounting have been found satisfactory. An explanation of the feasibility of the use of Si detectors in this temperature range in connection with experiments which require separation of $\alpha$-particle fine structure with long-term stability has been made. The results of these tests will be presented. A study of noise and resolution indicates that for alpha particles the smallest observed peak widths are substantially larger than those expected on the basis of electrical noise from the detector and amplifier. Equivalent electrical noise values of $\lesssim 3$ kev (full width at half maximum) have been found for a 40-mm² Si surface barrier detector at 77°K.

[1] F. J. Walter, J. W. T. Dabbs, and L. D. Roberts, Rev. Sci. Instr. 31, 756 (1960).

**A5. Pulse Rise Times in Semiconductor Particle Detectors.** J. W. T. DABBS AND F. J. WALTER, *Oak Ridge National Laboratory.*—Under certain circumstances, the charge-carrier transit times in semiconductor particle detectors can be quite short.[1] This presents the possibility of using such detectors in nanosecond timing applications. Even though the transit time is short, it is necessary to fulfill several conditions to obtain a short rise time at the input to the pulse amplifier. An estimate of the observable rise time requires that one con-

sider the time required to transmit information to the amplifier through the undepleted base material of the detector and through any contact or sheet resistances that may exist. By using an equivalent circuit previously developed,[1] we have made a detailed analysis of the pulse rise times and shapes to be expected under certain assumptions. The equations thus derived show that the amplifier rise time can approach the transit times if the amplifier input capacitance, series resistances, resistivity, and resistance of the undepleted base material are sufficiently small.

[1] F. J. Walter, J. W. T. Dabbs, and L. D. Roberts, Rev. Sci. Instr. 31, 756 (1960).

**A6. Post Acceleration After-Pulser for the Oak Ridge Pulsed Van de Graaff.** W. M. Good and R. F. King, *Oak Ridge National Laboratory.*—With ion sources presently available[1] it should be possible to obtain milliampere bursts of ions of 1 nsec and less duration without the complications and limitations of bunching. However, fundamental limitations prevent achieving the very short times by terminal pulsing alone when the ion beam is large or, for that matter, if the ions are heavy.[2] The limitations are reduced in magnitude if the pulsing is performed at high energy. To accomplish ion burst production at 1–3 Mev ion energy, at ion currents in excess of 1 ma, and not overload the Van de Graaff, an "after-pulser," synchronized with the terminal produced bursts, has been designed and built. The pulser has worked satisfactorily and is in routing use for the production of 2-nsec, 500-$\mu$a bursts of $He^3$. Details of the design, construction, and performance of this pulser will be presented.

[1] C. D. Moak, H. E. Banta, J. N. Thurston, J. W. Johnson, and R. F. King, Rev. Sci. Instr. 30, 694 (1959).
[2] T. K. Fowler and W. M. Good, Nuclear Instr. and Methods 7, 245 (1960).

**A7. A Permanent Magnet Spectrograph with Pre-Acceleration.*** R. G. Albridge† and J. M. Hollander, *University of California* (introduced by J. H. Hamilton, Jr.).—A 180° permanent field electron spectrograph with pre-acceleration was constructed. The acceleration of the electrons is produced by a 10-kv potential between source and aperture. The magnetic field strength is 50 gauss. With this instrument Auger electrons whose initial energies are less than 1 kev were detected.

* Supported by the U. S. Atomic Energy Commission.
† Now at Vanderbilt University.

**A8. Ion Focusing by Quadrupole Lens Pair in Mass Spectrometer.** Chih-Shun Lu and Howard E. Carr, *Auburn University.*—The focusing properties of a quadrupole lens pair have been studied with primary considerations for its use in a Nier-type mass spectrometer. Simple expressions of the lens equations are obtained by applying the special conditions for a mass spectrometer to the matrix formulations of quadrupole lens equations.[1] Numerical analysis of the lens equations has been carried out by an IBM-650 computer, and a resulting graph is given for determining the potentials on the lens system at different focusing conditions. Results are compared to those obtained by Giese[2] and Kinzer.[3]

[1] L. C. Teng, Rev. Sci. Instr. 25, 264 (1954).
[2] C. F. Giese, Rev. Sci. Instr. 30, 260 (1959).
[3] E. T. Kinzer and H. Carr, Rev. Sci. Instr. 30, 1132 (1959).

**A9. A Study of Thermal and Resonance Neutron Flux Detectors.*** George M. Jacks, *Clemson College* (introduced by J. R. Patterson).—Cadmium ratios CdR and self-shielding corrections $Q$ were obtained for neutron activation of various foils in the Standard Pile. Resonance activation integrals were computed by comparisons with gold using

$$RI = RI\frac{\sigma 2200^{\text{act}}(\text{CdR-1})\text{Au}Q\text{Au}}{\text{Au}\sigma 2200_{\text{Au}}{}^{\text{act}}(\text{CdR-1})Q}.$$

| Material | thermal cross section $\sigma 2200^{\text{act}}$ (barns) | resonance activation integral (barns) |
|---|---|---|
| Au-197 | 98.8 | 1558 |
| In-115 | 155±10 | 2639±133 |
| W-186 | 34±7 | 396±59 |
| Eu-151 | 1400±300 | 901±138 |
| Mn-55 | 13.3±0.2 | 14.0±0.3 |
| Lu-175 | 13.3 | 463±15 |
| Lu-176 | 2049 | 887±65 |
| Dy-164 | 2750±150 | 482±33 |

* Work supported by the U. S. Atomic Energy Commission.

**A10. Radiation Survey of the Berkeley 184-In. Cyclotron.** R. W. Boom, K. S. Toth, and A. Zucker, *Oak Ridge National Laboratory.*—Residual and induced radioactivities were measured at the 184-in. Berkeley cyclotron during November, 1960, to predict radioactivity problems connected with a high-intensity, 850-Mev accelerator. The five-day study was conducted along three principal lines: (1) general survey of radiation levels in the cyclotron vault, (2) activation of foils placed near the cyclotron, and (3) $\gamma$-ray spectra of the cyclotron gap region, including dee structure. Initial radiation levels were less than 8 r/hr and these dropped to about 10 mr/hr after 48 hr. Activities induced in (1) copper foils were $Cu^{64}$, $Co^{58}$; (2) iron foils were $Mn^{52}$, $Mn^{54}$, $Mn^{56}$; and (3) aluminum foils was $Na^{24}$. The $\gamma$-ray spectra from the gap region included two intense long-lived peaks at 510 and 810 kev (possibly $Co^{58}$). The preliminary conclusion is that a 100-$\mu$a 850-Mev cyclotron would have background (long lived) radiation less than 1 r/hr.

**A11. A Coincidence Timing Device.** Robert L. Hoover, *University of North Carolina.*—A device for determining the time between two successive events separated by $T \geqslant 10^{-14}$ sec is described. The proposed instrument makes use of the quanta occurring with the annihilation of positrons and electrons. Two collimated sources of electrons and positrons, respectively, are located 90° from each other in such a fashion that the electron and positron beams converge in a common area. $Z$-axis modulation is applied to both beams such that a packet of electrons and positrons is sent flying into each other, whence a certain number annihilate. The tentative plans for the instrument are reviewed as well as the cross section for annihilation. The uncertainty principle and its limitations also are noted.

## *Theoretical Physics, General Physics*

**B1. Velocity-Dependent Singlet Potentials.*** L. M. Simmons, Jr., and O. Rojo,† *Louisiana State University* (introduced by J. S. Levinger).—We assume a well-behaved nucleon-nucleon interaction[1] which consists of a static attractive part and a repulsive part depending on the square of the momentum operator $p$: i.e., $V(r)+(1/M)[p^2\omega(r)+\omega(r)p^2]$. The $^1S$ and $^1D$ phase shifts are calculated numerically (neglecting Coulomb interaction) from 20 Mev to 340 Mev, and the interaction potential adjusted to try to fit experimental values[2] of these phase shifts. Several good $^1S$ phase shifts have been

obtained. A fair fit to Breit's $^1D$ phase shifts (his $K_2$, YLAM) also is obtained with $V(r)=-55\exp(-r)$ Mev and $\omega(r)=5\exp(-3.6r)$, as shown below.

| Lab. energy | 20 | 100 | 180 | 260 | 340 | Mev |
|---|---|---|---|---|---|---|
| Calc. phase shifts | 0.031 | 0.132 | 0.140 | 0.116 | 0.080 | radian |
| Breit's values | 0.015 | 0.072 | 0.120 | 0.160 | 0.184 | radian |

* Supported in part by the National Science Foundation.
† Creole Foundation Fellow, now at Universidad Central de Venezuela.
[1] A. Green, University of Birmingham, (private communication); Razavy, Rojo, and Levinger, *Proceedings of the International Conference on Nuclear Structure* (University of Toronto Press, 1960), p. 128.
[2] G. Breit, M. H. Hull, Jr., K. E. Lassila, and K. D. Pyatt, Jr., Phys. Rev. 120, 2227 (1960).

**B2. Phenomenological Nuclear Potentials for Closed Shell Nuclei.** J. L. FOWLER, *Oak Ridge National Laboratory.*—For a neutron bound to closed shell nuclei, the low-lying states appear to arise from the interaction of a neutron with an average potential. In the case of $O^{16}$ the even parity bound states and even parity scattering phase shifts can be fitted with a Woods-Saxon potential $V(r)=-V_0[1+\exp(r-R/A)]^{-1}$ having a state-dependent depth $V_0$.[1] If the velocity dependence is introduced by the reduced mass formalism, $m=m_0[1+KV(r)]^{-1}$, the experimental data can be reproduced by use of the following parameters: $A=0.56$f, $R=2.228$f, $V_0=150.11$ Mev, and $K=1.25/V_0$ Mev$^{-1}$, with the constant multiplying the Thomas spin orbit term $=5.64$. The $2s$ and $1d$ wave functions for the case of the reduced mass formalism differ somewhat from those found for the state-dependent potential. The position of several of the bound states of $Pb^{209}$ have been fitted with the Woods-Saxon potential.[2] An extension of the shell model analysis to the calculation of phase shifts for the scattering of neutrons from $Pb^{208}$ will be discussed.

[1] E. G. Corman and J. L. Fowler, Bull. Am. Phys. Soc. 5, 34 (1960).
[2] J. Blomqvist and S. Wahlborn, Arkiv. Fysik 16, 545 (1959).

**B3. Configuration Space Treatment of Many Boson Systems.** V. H. SMITH AND H. A. GERSCH, *Georgia Institute of Technology* (introduced by L. D. Wyly, Jr.).—The properties of a Bose system of particles with repulsive interactions have been treated by using perturbation theory in the second quantization formalism[1] as well as by considering the wave function in configuration space,[2] using the theory of cluster expansions. The latter treatment is now modified by including those higher order diagrams consistent with the pair excitation approximation which were previously omitted. The cluster expansion is made in powers of a parameter analogous to the classical fugacity. Its definition automatically accounts for the depletion of the ground state. The resulting expectation value for the Hamiltonian is in agreement with that of Girardeau and Arnowitt[3] obtained by field-theoretical methods for states of pair excitation type. The extension of this method to include contributions from momentum conserving groups of three and more particles will be discussed.

[1] T. D. Lee, K. Huang, and C. N. Yang, Phys. Rev. 106, 1135 (1957)
[2] H. A. Gersch and V. H. Smith, Phys. Rev. 119, 886 (1960).
[3] M. Girardeau and R. Arnowitt, Phys. Rev. 113, 755 (1959).

**B4. New Representation of Spin Operators.** JOHN ROBERT SHEWELL, *Auburn University.*—The angular momentum commutation rules and the condition that the operators be self-adjoint are considered as the defining relations for three operators. One asks if there exist three operators, $L_1$, $L_2$, and $L_3$, satisfying these definitions, these operators being expressible in terms of one momentum operator and its conjugate coordinate operator. The answer is in the affirmative. Among other things, this leads to a new representation of spin operators. The properties of these operators and their characteristic functions will be discussed.

**B5. Minimum Space-Time Extension of Events.** I. BLOCH, *Vanderbilt University.*—There are indications that two interacting particles of equal mass necessarily interact over a four-dimensional volume equal to at least the fourth power of their Compton wavelength, where the volume is expressed in terms of the usual coordinates of quantum theory. Since a space-time coordinate system is physically defined only with reference to the events that constitute the coordinate points, it appears that the coordinates of quantum theory may not have perfectly precise physical meaning, and that the "localized" states discussed by Newton and Wigner *et al.*[1] may be indistinguishable from the presumably nonexistent delta-function states. A study is being made of two reciprocal sets of space-time position eigenvectors which are eigenvectors of a non-Hermitian operator $\mathbf{x}$ and its adjoint, the vectors of either set being nonorthogonal over a small space-time region.

[1] T. D. Newton and E. P. Wigner, Revs. Modern Phys. 21, 400 (1949). L. L. Foldy and S. A. Wouthuysen, Phys. Rev. 78, 29 (1950).

**B6. Lattice Thermal Conductivity Calculations.** JOHN H. HENKEL, *University of Georgia.*—The anharmonic potential Einstein type solid state model previously used by the writer is adapted to calculate thermal conductivities. This adaptation is performed by assuming that the vibrations of atoms perturb neighboring atoms and thereby induce transitions. The net effect is an energy transfer. The thermal dependence of the thermal conductivity then has the form

$$K=\frac{Ax^2(e^{2x}+1)(e^x-1)^2}{(e^{2x}-1)^2}e^x,$$

where $x=\theta/T$ and where $A$ and $\theta$ are constants determined in terms of the potential energy expression between atoms.

**B7. *F*-Center Energy Levels and Wave Functions for a Point Charge Rock Salt Lattice.** E. F. SIECKMANN, *University of Kentucky* (introduced by O. T. Koppius).—The ground state and first two excited state energies and wave functions have been calculated for an electron trapped by a negative ion vacancy in a rigid rocksalt type lattice consisting of point charges. The potential energy of the electron was expanded in a series of Kubic Harmonics,[1] and the Schroedinger equation for the problem was separated by an expansion of the wave function in a series of Kubic Harmonics of the appropriate symmetry type. The resulting simultaneous second-order radial differential equations were integrated numerically under the assumption that all spherical harmonics of order greater than four are negligible, by power series expansion, and gave the energy eigenvalues and associated radial wave functions. The results are compared with the results of the effective mass and other approximations.

[1] Fred C. Von der Lage and H. A. Bethe, Phys. Rev. 71, 612 (1947).

**B8. Equation of State, Specific Heats, and Elastic Coefficients of Crystalline Sodium Chloride.** RICHARD S. BELL AND JOHN. H. HENKEL, *University of Georgia.*—An interaction potential of the form $A/r^9+B/r^6\pm e^2/\mu r$ is assumed between two ions of crystalline sodium chloride. The dielectric constant is assumed to be unity, and the constants $A$ and $B$ are calculated using the heat of sublimation and the lattice constant at temperature $T=0$°K and pressure $p=0$. If it is assumed that each ion moves in a potential field due to all the others at rest in their mean positions, the energy eigenvalues are calculated considering both harmonic and anharmonic modes of vibration by using the perturbation theory for a harmonic oscillator. The partition function for each ion is obtained, and the equation of state is derived. The specific heats are computed as a function of temperature from 0°K to the melting point and are found to fit experimental data very well particularly in the temperature range 50° to 600°K. The elastic coefficients $C_{11}$, $C_{12}$, and $C_{44}$ are calculated by Born's method without neglecting the part played by thermal energy.

**B9. An Analogy for Time Lag in Pressure Measuring Systems.** RAY KINSLOW, *Tennessee Polytechnic Institute*, AND MAX KINSLOW, *Aro, Inc.*—Pressures are often measured by means of small orifices or probes connected to sensing elements by relatively long lengths of tubing. If the pressure to be measured is varying, the pressure indicated is not the true pressure. There is an analogy between the pressure variations in such a system and the depth of a liquid flowing between parallel walls. By observing the flow of liquid between transparent plates, information may be obtained that would be of value in the design and analysis of pressure measuring systems as it provides a visual means of observing the changes in pressure and velocity throughout the system. The liquid may be colored and photographed by means of a movie camera to give a record of the propagation of the liquid waves which are analogous to the pressure waves of the gas in a circular tube. This also serves as an effective teaching aid as it provides a means of demonstrating the response to pressure variations. By applying input functions such as sinusoidal, impulse, or step functions, dynamic errors such as amplitude changes, phase shift, overshoot, and rise time may be observed.

**B10. Ripples on Very Shallow Water.** R. D. EDGE, *University of South Carolina* (introduced by A. P. French).—Optical methods were employed to investigate ripples on water 0.1 to 0.4 cm deep. Their velocity was in agreement with infinitesimal wave theory up to wavelengths of 2 cm, beyond which the waves broke up. The particle motion in the surface was elliptical, but the precise dimensions of the orbits were found to disagree with infinitesimal theory, possibly because the surface does not follow the water underneath. The ripples initially had a negative conoidal profile (in agreement with Korteweg and De Vries[1]) which decayed rapidly to approximate a sine wave. The negative solitary wave (i.e., surface depression) which these authors predicted was discovered but proved difficult to generate. A type of solitary ripple system with ripples running ahead of a discontinuity (the analog of a hydraulic jump with its associated undulations) could be produced readily and was observed to propagate without change of form. The viscous decay of ripples was found to be in good agreement with the theory of Biesel.[2]

[1] D. J. Korteweg and G. De Vries, Phil. Mag. (5) 39, 422 (1895).
[2] F. Biesel, Houille bl. 4, 630 (1949).

## *Invited Paper*

**C1. The Mössbauer Effect.** HORST WEGENER, *Oak Ridge National Laboratory.*

## *Symposium on Internal Conversion*

### *Invited Papers*

**D1. Anomalous $E1$ Conversion Coefficients.** J. M. HOLLANDER, *University of California, Berkeley.*
**D2. Anomalies in $E2$ Conversion Coefficients.** J. H. HAMILTON, *Vanderbilt University.*
**D3. Theory of Internal Conversion.** M. E. ROSE, *Oak Ridge National Laboratory.*

### *Contributed Papers*

**D4. Decay of Indium 116.** DONALD L. CLAPP AND JOHN D. FRENCH, *Auburn University.*—A scintillation spectrometer, employing photographic recording of coincidence spectra, has been used to examine the decay of indium 116. Gamma-gamma coincidence spectra have been obtained which are consistent with previously proposed decay schemes. Additional gamma-ray transition between established levels are indicated by the observed coincidences.

**D5. An Absolute Determination of the $He^6$ $\beta$-Decay Energy.** C. H. JOHNSON, FRANCES PLEASONTON, AND T. A. CARLSON, *Oak Ridge National Laboratory.*—Measurements on the recoil energy spectrum of $Li^6$ ions following the $\beta$ decay of $He^6$ yielded an absolute determination of the $He^6$ $\beta$-decay energy. Since the recoil spectrum drops sharply to zero, it is possible to make a precise determination of its end point and, hence, to find the decay energy. Two types of measurements were made. In the first, which gave a value of $3.510\pm0.006$ Mev for the decay energy, the spectrometer was calibrated in a conventional manner with a $(He^4)^+$ ion source whose potential was measured by a precision resistance divider, potentiometer, and standard cell. In the second method, two spectra were observed, one with the $He^6$ source volume at the same potential as the spectrometer and the other with the source raised to a potential sufficient to shift the end point to twice its original energy. Measurement of this potential gave an energy calibration leading to a decay energy of $3.508\pm0.006$ Mev. Uncertainties in the voltage measurements which are common to both results are negligible compared to the quoted errors. The weighted average of the two observations is $3.509\pm0.004$ Mev.

**D6. Fermi Plot Analysis of Beta-Ray Spectra: A Computer Technique.** ROY A. PARKER, CHARLES L. PEACOCK, JR., AND MAX GOODRICH, *Louisiana State University.*—A program has been written for an IBM-650 with indexing registers and floating point arithmetic which determines the end-point energy and intensity of allowed beta transitions. The program operates on the raw data from any beta-ray spectrometer, and it determines the calibration of the spectrometer and corrects for the decay of the isotope. The modified Fermi function is computed for each momentum processed, and it is not interpolated from previously stored tables. Computation of the modified Fermi function is made possible by the ability to compute the complex gamma function to a high degree of accuracy. This was accomplished by using Taylor's expansion in polygamma coefficients and Stirling's asymptotic expansion. $\Gamma(x+iy)$ may be computed by one of the above methods, depending on its position in the complex plane, for all $\pm x$ and $\pm y$. If $\Gamma(x+iy)=V_1+iV_2$, then $V_n(n=1,2)$ is accurate to six figures when $|V_n|\geq 1$ or to six decimals when $|V_n|<1$. The allowed beta transitions of $Ba^{140}-La^{140}$ have been analyzed by this program, and it separates one beta ray from the spectrum in less than 15-min running time. A program including the analysis of forbidden transitions is under investigation.

**D7. Interpretation of Beta-Gamma Angular Correlation in the Decay of $Eu^{154}$.*** H. G. DULANEY, L. D. WYLY, AND C. H. BRADEN, *Georgia Institute of Technology.*—Additional data on the (1885-kev beta group) (123-kev gamma) directional correlation[1] in the decay of $Eu^{154}$ confirm that the ansiotropy is less than in the comparable transition in $Eu^{152}$. Comparison of the decays suggests that attenuation of the ordinary first forbidden matrix elements relative to $B_{ij}$ is less marked in $Eu^{154}$. For $Eu^{154}$ we find $A_2$ in the range $-0.11$ to $-0.16$ for beta energies from 1200 to 1550 kev. A value of approximately 3 for the single matrix element parameter $Y$ is consistent with the directional correlation data but is outside the results of the beta spectral shape measurement.[2] A one-parameter description of the directional correlation and the beta spectral shape is valid only if the $B_{ij}$ matrix element is much larger than ordinary first forbidden matrix elements or if only a single ordinary matrix element is retained, e.g., the "modified $B_{ij}$ approximation."

* Supported in part by the National Science Foundation.
[1] H. Dulaney, L. D. Wyly, and C. H. Braden, Bull. Am. Phys. Soc. **4**, 391 (1959).
[2] L. M. Langer and D. R. Smith, Phys. Rev. **119**, 1308 (1960).

**D8. The $Au^{198}$ Beta Spectrum and 412-kev $K$ Conversion Coefficient.*** J. H. HAMILTON AND R. V. STOCKENDAL, *Vanderbilt University*, AND D. C. CAMP, L. M. LANGER, AND D. R. SMITH, *Indiana University.*—Recent measurements of the beta spectrum shape as well as $K$ conversion coefficient as measured by the peak to beta spectrum ratio method are not in agreement.[1] A careful study of the $(2- \rightarrow 2+)$ $Au^{198}$ beta spectrum has been made to look for small effects in the shape factor and to study the $K$ conversion coefficient of the 412-kev transition. Above 450 kev the spectrum is essentially statistical, but an excess of electrons is clearly observed in going to lower energies. The empirical shape factor $(1+b/W)$ with $b \cong 0.2$ offers a better fit. The latter shape factor is expected for a once forbidden, nonunique transition. From a preliminary analysis, our value of $\alpha_K$ should be between 0.027 and 0.028 depending on the shape factor choice (errors are $\cong 0.001$ in each case).

* Supported in part by grants from the National Science Foundation and A.E.C. and Office of Naval Research.
[1] Wapstra, Nijgh, Salomons-Grobben, and Ornstein, Nuclear Phys. 9, 538 (1958/59); DeVries, Bleeker, and Salomons-Grobben, *ibid.* 18, 454 (1960).

## *Electron Spin Resonance, Solids, Plasmas, and Gases*

**E1. Thermal Relaxation in Fluorine Gas.*** F. D. SHIELDS, *University of Mississippi.*—Sound absorption and velocity measurements have been made in fluorine gas at room temperature. The measurements were made on plane progressive waves confined to a Pyrex glass tube of 1.73 cm i.d. The frequency employed was 5 kc, and the pressure varied from 6 cm. to atmospheric. The measurements were corrected using the classical Kirchhoff equation for losses to the tube walls. After these corrections an absorption peak and dispersion region were observed centered at 8 kc per atmosphere. This indicates a relaxation time for the passage of energy between vibration and translation of 22 μsec. The peak of the absorption curve was about 10% higher than predicted from specific heat data. The cause for this high value is now under investigation. The velocity dispersion data fit the relaxation dispersion equation to within the accuracy of the data. Unsuccessful attempts at high temperature measurements have yielded some interesting laboratory notes on the techniques of handling fluorine.

* Under contract with the Office of Naval Research.

**E2. Measurements of Electron Avalanche Space Charge Accumulation in Gaseous Breakdowns.** H. W. KENDALL* AND JOHN W. FLOWERS, *University of Florida.*—A method of detecting and measuring the build-up of space charge by electron avalanches in gaseous breakdowns during the formative time lag will be presented. The gas between the electrodes of a discharge gap is subjected to an electric field of sufficient intensity to produce a gaseous breakdown. Prior to the breakdown, the electric field is reversed in direction, but unchanged in magnitude, and the effect of the space-charge-created electric field on the time lag of the subsequent breakdown is determined. Measurements, using overvoltages less than 0.05%, indicate that, as has been theoretically predicted by Miyoshi,[1] for a uniform field at atmospheric pressure relatively little space charge develops during at least the first 95% of the formative time lag. In nonuniform electric fields large space charge fields arise and may be detected quite early in the formative time.

* National Science Foundation Fellow. Now at the University of South Florida.
[1] Y. Miyoshi, Phys. Rev. **117**, 355 (1960).

**E3. Plasma Power Supply.** CHARLES CASON AND T. A. BARR, JR., *Army Rocket and Guided Missile Agency.*—A simple theory makes it possible to estimate the power output of a plasma which has a thermal gradient. Two collecting electrodes, which are cooled to prevent thermionic emission, are assumed to be placed in plasma regions of unlike temperature where local thermodynamic equilibrium prevails. The short-circuit current is found to be dependent primarily upon differences in random ion currents at each electrode while open circuit voltage depends upon the type of gas utilized and the difference in electron temperatures. Calculations for argon at 1 atm and electron temperatures of 20 000°K at one collector and 10 000°K at the other show that a maximum power of 700 w per $cm^2$ of collector electrode surface may be obtained for a carefully selected load. Graphs of output current vs voltage and output power vs load will be presented for the above example.

**E4. A Resonance Type Mechanism for Producing the 4685.7 A Line in Plasmas Below 20 000°K.** T. G. ROBERTS AND W. L. HALES, *Army Rocket and Guided Missile Agency.*—The spectral line at 4685.7 A is frequently identified at the Paschen-like alpha line of He II even in plasmas from plasma jets where the temperature is less than 20 000°K. It is suggested that this line is a nitrogen line from the transition $3d\,^2P_{\frac{1}{2}} - 3s\,^4P_{\frac{1}{2}}$. A resonance type mechanism for producing nitrogen in the $3d\,^2P_{\frac{1}{2}}$ state is proposed. This mechanism requires the heat of dissociation on $N_2^+$ to be taken as $D_0^0(N_2^+) = 6.341$ ev as advocated by Herzberg instead of the value $D^0(N_2^+) = 8.724$ ev as advocated by Pearse and Gaydon.

**E5. Two-Stream Instability in a Finite Plasma.*** GORDON K. SOPER AND EDWARD G. HARRIS, *The University of Tennessee.*—The general dispersion relation is derived for small amplitude waves in a fully ionized plasma confined between two infinite parallel planes. This derivation is made in the first case assuming no magnetic field and secondly with a magnetic field along the direction of flow of the electrons. No distribution of velocity of the plasma is used—i.e., it is assumed that the plasma is cold. In the absence of the magnetic field three unstable modes exist. One of these is the one found in the infinite plasma case. The other two involve charges on the plasma surface. The analysis of the magnetic field case is still in progress.

* Supported by the U. S. Atomic Energy Commission.

**E6. Thermal Annealing of *F* Centers in Gamma-Irradiated KBr.*** W. B. JENNINGS, JR.,† AND W. C. MALLARD, *Emory University*.—Cleaved Harshaw KBr crystals were irradiated with gamma rays from a 200-C cobalt source at room temperature. Initial *F*-center concentrations of approximately $3\times10^{16}$/cm$^3$ were obtained, while negligible *R* and *M* bands were observed. Alternate pulse anneals and optical transmission measurements at room temperature were made until the *F*-band transmission increased ~50%. Transmission measurements were made in the 400 to 1300 mμ range. One specimen was annealed at each of the following temperatures: 121, 132, 138, 143, and 150°C. *F*-center concentrations were determined by both band area integration and the use of Smakula's equation. Bleaching consisted of a fast initial stage, in which ~10% of the *F* centers were annihilated, and a slow first-order process. The *R* and *M* bands were bleached in the initial thermal anneal and were not enhanced by the bleaching of the *F* centers. The slow bleaching process can be described approximately by a time constant of the form $T=T_0\exp(\epsilon/\kappa T)$, where $T_0\cong10^{13}$ sec and $\epsilon=0.1$ to 0.2 ev. Possible mechanics for the bleaching process will be discussed.

* Supported in part by the National Science Foundation.
† Present address: Redstone Arsenal, Huntsville, Alabama.

**E7. Radiation Effects on Deep-Level Impurity States in Ge.** R. F. BASS, J. W. CLELAND, AND J. H. CRAWFORD, JR., *Oak Ridge National Laboratory*.—The change in electronic properties of semiconductors during irradiation and during subsequent annealing depends critically on the type and energy of the initial bombarding particle and on the initial type, carrier concentration, defect concentration, and chemical impurity in the material. Substitutional Te acts as a double donor in *n*-type Ge. Extensive experiments have indicated that introduction of isolated Frenkel-type defects by $Co^{60}$ $\gamma$ irradiation and any subsequent removal of such defects by vacuum annealing at 450°C has no apparent effect on the concentration and donor action of the Te; however, the introduction and subsequent removal or rearrangement of fast-neutron induced lattice defects under the same annealing conditions totally cancels the apparent concentration and donor action of the Te. This effect has not been observed previously with normal donor or acceptor chemical impurities, nor was it observed in Ge that was doped with Cu acceptor impurities.

**E8. Kinetics of the Disorder-Order Transformation in AuCu.** W. EDWARD GETTYS, *Clemson College* (introduced by J. R. Patterson).—A preliminary investigation of the disorder-order transition in AuCu indicates that the transformation time is considerably less than that reported by Borelius and co-workers.[1] An evacuated high-temperature x-ray diffraction chamber is being used in the study. High heating and cooling rates allow rapid changes of sample temperature. Two types of transformation, depending on the ordering temperature, were observed by Borelius; at lower temperatures (290°C) the disordered diffraction maxima broadened and changed continuously to the ordered line positions. In the present work no evidence of this process has been observed as yet. At the ordering temperatures investigated thus far, the entire transformation is effected in less than 6 min.

[1] G Borelius, J. Inst. Metals **74**, 17 (1947).

**E9. A Galvanomagnetic Investigation of the Hole Component of the Fermi Surface of Bismuth.*** J. R. SYBERT,† C. G. GRENIER, AND J. M. REYNOLDS, *Louisiana State University*.—The magnetoresistance and Hall effect in a single crystal of bismuth has been measured in the interest of obtaining a more complete analysis of the Fermi surface. Measurements were made at 1.8°K in magnetic fields ranging to 16 kgauss. The galvanomagnetic voltages were recorded and studied for periodicity at various orientations of the magnetic field in order to map the Fermi surface. The portion of the Fermi surface mainly responsible for the galvanomagnetic oscillations can be described to a first approximation by an ellipsoid of holes oriented with its major axis along the axis of three-fold symmetry of the crystal. The ratio of major to minor axis of the ellipsoid is approximately 3.8. Various data for this ellipsoid are compared to results of other types of measurement (de Haas-van Alphen effect, cyclotron resonance, anomalous skin effect) on bismuth. In particular, the earlier discrepancy between the de Haas-van Alphen data of Schoenberg[1] and the galvanomagnetic data of Reynolds *et al.*[2] has been resolved.

* Supported in part by the Office of Ordnance Research, U. S. Army.
† National Science Foundation Faculty Fellow.
[1] D. Schoenberg, Proc. Roy. Soc. (London) **A170**, 341 (1939).
[2] J. M. Reynolds, W. H. Hemstreet, T. E. Leinhardt, and D. D. Triantos, Phys. Rev. **96**, 1203 (1954).

**E10. Quantitative Analysis of Vanadium and Free Radical Concentrations in Crude Petroleum by Electron Spin Resonance.** E. M. ROBERTS, *Mobil Oil Co.* (introduced by W. C. Skinner).—It has been observed that viscosity differences between samples of crude petroleum create discrepancies in the analysis of vanadium by the esr method.[1] We have developed a simple method for performing a quantitative analysis of vanadium in crude petroleum, using esr data, which eliminates the above discrepancies due to varying viscosities. Several concentrations of a vanadyl porphyrin standard dissolved in castor oil were prepared. The concentrations ranged from 100 ppm to 1 ppm. The standards and the crude petroleum were then solidified by passing pre-cooled nitrogen over the sample tubes. The spectra were recorded, and the peak heights were measured. It is necessary to solidify both standard and unknown since the vanadyl porphyrin molecule used as a standard is much smaller than the large specie found in crude petroleum. The free radical found in petroleum shows no viscosity effect, and its analysis may be performed at room temperature.

[1] A. J. Saraceno *et al.*, Am. Chem. Soc. Abstracts, 138th meeting (1960).

**E11. Paramagnetic Properties of $H_2^+$ from Exact Wave Functions and Nonsingular Operators. Effect of Nuclear Motion.** E. M. ROBERTS AND M. R. FOSTER, *Mobil Oil Co.* (introduced by W. C. Skinner).—The anisotropy of the spectroscopic splitting factor arising from the spin-orbit interaction has been calculated and shown to be negligible. Also, the first-order energy correction due to the anisotropic hyperfine interaction has been computed for the ground state. In the two latter calculatons, exact operators were used. The advantage of using exact operators lies in the fact that they give rise to convergent integrals. The spin-orbit interaction may be written, to a good approximation, as $\lambda\mathbf{L}\cdot\mathbf{S}$ regardless of the cylindrical symmetry of the molecule. The isotropic esr spectrum was calculated, taking into account the motion of the nuclei. Since the vibrational frequency is much greater than the esr transition frequency, each hyperfine transition frequency will be an average over the nuclear motion. Shifts of 10 to 24 Mc from the equilibrium configuration frequencies are calculated.

***Invited Paper***

**E12. Modulation of Light at Microwave Frequencies.** P. S. PERSHAN, *Harvard University*.

## Nuclear Physics

**F1. Reaction Cross Sections for $Zn^{64}(n,2n)Zn^{63}$ and $Zn^{64}(n,p)Cu^{64}$.*** L. A. RAYBURN, *Argonne National Laboratory and University of Georgia.*—Cross sections for these reactions have been measured at several incident neutron energies between 13.5 Mev and 19.5 Mev. An experimental technique was used in which the two 511-kev gamma rays from the annihilation of positrons in the irradiated samples were counted in coincidence by using two NaI scintillation spectrometers. The value of the $Zn^{64}(n,2n)Zn^{63}$ reaction cross section increased from 75 mb at 13.5 Mev to a maximum of approximately 375 mb at about 18.5 Mev. The value of the $Zn^{64}(n,p)Cu^{64}$ reaction cross section decreased from 215 mb at 13.5 Mev to approximately 120 mb at 19.5 Mev. Where these measurements overlap those of other investigators, the values are in agreement.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**F2. Fast Neutron-Induced Reactions in Miobium and Zirconium.** D. R. KOEHLER, W. L. ALFORD, AND C. E. MANDEVILLE,* *Redstone Arsenal.*—The recently reported activity[1] induced by neutron bombardment of niobium has been produced by 14-Mev neutrons on both niobium and zirconium and by neutrons of energy less than 6 Mev on niobium. In each case chemical separation showed the activity to be due to an yttrium isotope. Two coincident gamma rays of energies, 190 kev and 485 kev, with half-life 3.1±0.1 hr were observed in agreement with earlier values.[1] The activity appears very similar to that which has been previously attributed to the $Y^{93}$ decay scheme.[2] However, threshold considerations and the failure to observe by means of a thin window Geiger counter any beta emission associated with this gamma activity point to an isomeric state of $Y^{90}$. Additional experiments are under way using separated isotopes of zirconium in an effort to clarify the isotopic assignment.

* Address: Physics Department, University of Alabama.
[1] M. Bocciolini, G. DiCaporiacco, L. Foa, and M. Mando, Nuovo cimento **XVI**, 1804 (1960).
[2] Wayne A. Cassatt, Jr., and W. Wayne Meinke, Phys. Rev. 99, 760 (1955).

**F3. Measurement of the Lifetime of the 77 kev Excited State of $Au^{197}$ by the Mössbauer Method.** L. D. ROBERTS, *Oak Ridge National Laboratory,* AND J. O. THOMPSON, *University of Tennessee*—An electromechanical transducer for Mössbauer experiments, capable of operating in the approximate velocity range 0 to 40 cm/sec and in an approximate temperature range 4°K–400°K, has been constructed. In a preliminary study the Mössbauer spectrum of $Fe_2O_3$ was measured with results in good agreement with those of Kistner and Sunyar.[1] Using a $Pt^{197}$ metal source prepared from an enriched $Pt^{196}$ sample, in conjunction with a $Au^{197}$ absorber, the Mössbauer absorption spectrum at 4°K has been observed. The result gives a linewidth equivalent to a lifetime of 2±0.2 mμsec for the 77 kev excited state. This is in agreement with a previous measurement by Sunyar.[2] The apparatus and measurements will be described.

[1] Kister and Sunyar, Phys. Rev. Letters, 4, No. 8, 412 (1960).
[2] A. W. Sunyar, Phys. Rev. 98, 653 (1955).

**F4. Analysis of $(n,n'\gamma)$ Differential Cross Sections and the Study of $Mn^{55}$ Levels.*** M. T. MCELLISTREM AND J. W. BORING, *University of Kentucky.*—Differential cross sections for gamma rays following inelastic neutron scattering to the first excited states of $Fe^{56}$, $Mg^{24}$, and $Pb^{206}$ are found to be in fair agreement with the predictions of the Hauser-Feshbach model. Measured ratios of the cross sections to the second and third excited states of $Fe^{56}$ are also compared with the predictions of this model. Calculated cross sections are obtained with the expression of G. R. Satchler,[1] using the diffuse surface complex well of Beyster, *et al.*[2] to describe the neutron-nucleus interactions. Gamma rays from the $Mn^{55}$ $(n,n'\gamma)$ reactions have been studied for transitions from the second and third excited states to the first excited state. The transitions are both shown to be $E2$. Since the first excited state has been assigned as $7/2^-$, the second and third excited states must be odd parity and have spins $3/2 \leqq I \leqq 11/2$. A more detailed analysis of the possible spin assignments, based upon the knowledge of the cross sections, will be presented.

* This work supported in part by the U. S. Atomic Energy Commission.
[1] G. R. Satchler, Phys. Rev. 104, 1198 (1956); M. Hosoe and S. Suzuki, J. Phys. Soc. Japan 14, 699 (1959).
[2] Beyster, Scrandt, Wall, and Salmi, La-2099 (April, 1957).

**F5. $(n,\gamma)$ Angular Correlations from $Be^9(\alpha,n)C^{12}$.*** T. DAZAI,* J. U. KJELLMAN,† AND J. H. NEILER, *Oak Ridge National Laboratory.*—Angular correlation measurements have been made of the reaction $Be^9(\alpha,n)C^{12*}$ $(\gamma_{4.43})C^{12}$ using associated particle time-of-flight techniques. The bombarding energy was 3.35 Mev in a region which shows no evidence of resonances. The target thickness was approximately 50 $\mu g/cm^2$. Plastic and NaI(Tl) scintillators were used for neutron and $\gamma$-ray detectors. Fast signals from the detectors operated a time-to-pulse height converter, the output of which was gated into a multi-channel analyzer by coincident single-channel outputs from the slow, energy selection system. Measurements were made by movement of the $\gamma$-ray detector with the neutron counter fixed at each of the angles: 10°, 20°, 75°, and 135° from the beam direction. The angular correlations were observed both in the reaction plane and in two, planes perpendicular to it, one parallel, the other perpendicular to the axis of symmetry of the correlation curve in the reaction plane.

* Guest scientist on leave from Tokyo Institute of Technology, Tokyo, Japan.
† Guest scientist on leave from Research Institute of National Defense, Sweden.

**F6. Coulomb Excitation of States in $V^{51}$, $Zn^{67}$, $Fe^{57}$, $Ge^{73}$, and $Ni^{61}$.** R. C. RITTER,* P. H. STELSON, F. K. MCGOWAN, AND R. L. ROBINSON, *Oak Ridge National Laboratory.*—$Ne^{20}$ ions with energies of 8- to 15-Mev were used to Coulomb-excite low-lying states in several odd-$A$ nuclei. The $Ne^{20}$ ions were obtained by the acceleration of doubly and triply ionized $Ne^{20}$ by the 5.5-Mv Van de Graaff. A PIG-type ion souce was used to enhance the output of multiply charged ions. Thick target $\gamma$-ray yields were measured to extract values for $B(E2)$. $\gamma$-ray angular distribution measurements were made to get information on spin and multipolarity assignments. The rather strong anisotropies observed for the 320-kev $\gamma$ rays from $V^{51}$ and the 184-kev $\gamma$ rays from $Zn^{67}$ lead to unique assignments. The spin of the 320-kev state of $V^{51}$ is 5/2 and the mixing ratio $\delta$ $[=(E2/M1)^{\frac{1}{2}}]$ is $+0.52\pm0.07$. Strong evidence is found against a previous assignment of $5/2^1$ for the spin of the 184-kev state in $Zn^{67}$. The observed anisotropy requires spin of 3/2. The value for $\delta$ is $+0.51\pm0.04$. The value for $\delta$ combined with the observed $B(E2)$ gives a total mean lifetime in good agreement with that measured by Holland and Lynch.[2]

* ORINS Fellow from the University of Tennessee.
[1] L. H. Th. Rietjens and H. J. Van den Bold, Physica 21, 701 (1955).
[2] R. E. Holland and F. J. Lynch, Bull. Am. Phys. Soc. 4, 232 (1959).

## Invited Papers

**F7. Current Nuclear Studies with the Florida State University Tandem Accelerator.** G. M. TEMMER, *Florida State University.*

**F8. Vibrational States in Nuclei.** P. H. STELSON, *Oak Ridge National Laboratory.*

## *Spectroscopy and Related Matters*

### *Invited Papers*

**G1. Gaseous Optical Masers.** W. R. BENNETT, JR., *Bell Telephone Laboratories.*

**G2. Pressure Modulation of Infrared Emission and Absorption.** DUDLEY WILLIAMS, *Ohio State University.*

### *Contributed Papers*

**G3. Infrared and Raman Spectra of $HPO_2F_2$.** DENVER JONES AND ERNEST JONES, *Vanderbilt University.*—The infrared spectrum of gaseous $HPO_2F_2$ has been investigated from 650 to 5000 $cm^{-1}$, and the Raman spectrum of the liquid has been obtained using the 4358 A line of mercury for excitation. The spectra have been interpreted on the assumption that the molecule has $C_s$ symmetry. Eight of the possible twelve fundamental vibrations have been assigned with reasonable certainty. Eighteen combination and overtone bands have been explained on the basis of the proposed fundamentals.

**G4. New Measurements on $\nu_2$ of $CO_2$.*** A. H. NIELSEN AND WILLIAM F. HERGET, *The University of Tennessee.*—The fundamental mode $\nu_2$ of $CO_2$ at 4.3 $\mu$ has been re-examined under high dispersion in a vacuum grating spectrometer equipped with a Reeder thermocouple and a 7500 lines-per-inch Bausch and-Lomb grating. The spectrometer tank was pumped down to a pressure of about 40 $\mu$ and $CO_2$ was admitted to a pressure of 1 mm. The total optical path in the spectrometer is about 8.5 m. At this pressure and path length the $C^{12}O_2$ lines absorb about 40% at the peak. Slit openings represent about 0.1 $cm^{-1}$. Lines of $C^{13}O_2$, $C^{12}O_2$, and $C^{12}O^{16}O^{18}$ are easily seen, and their frequencies are being determined in a vacuum by means of a comparison spectrum of neon lines from a hollow cathode discharge in higher orders of the grating. The molecular constants obtainable from this band will be redetermined.

* Supported by the U. S. Air Force Cambridge Research Center.

**G5. Preliminary Results in the Study of the Shapes and Intensities of Lines in the Infrared Spectrum of HF.*** WILLIAM F. HERGET, R. J. LOVELL, W. E. DEEDS, N. M. GAILAR, AND A. H. NIELSEN, *The University of Tennessee.*—The line shapes measured in the infrared spectral region are distorted from their true shapes by the effects of finite slitwidth and polychromatic source. An interesting and difficult problem is to determine the true line shapes from measured line shapes. Fundamental to this study is the use of a high-resolution spectrometer to record the spectra and to determine precisely the slit function. The proper numerical techniques must be developed to reduce the measured line data and the slit function to the true line data. The HF molecule has been chosen as nearly ideal for this study because of the simple spectrum, the wide spacing between the lines, and the great variation of line width with $J$ number. A large number of lines in the HF spectrum have been measured for different path lengths and pressures. The positions of these lines have been determined precisely, and the shapes have been corrected to the true shapes. The equivalent widths of many of these lines have been calculated. The half-widths and intensities have been obtained from the equivalent widths. A preliminary report on these measurements and calculations will be presented.

* Supported by the U. S. Air Force Cambridge Research Center.

**G6. A Systematic Experimental Approach to Band Intensities in Infrared Spectroscopy.** NELSON FUSON, *Fisk University.*—Spectroscopists often need to obtain a solution spectrum of a sample for structural analysis or for identification purposes. Frequently several false starts are made before a good spectrum is obtained. This paper will summarize information on absolute band intensities of characteristic vibrations of structural subgroups and will present a method for assuring good solution spectra of most samples the first time they are studied.

**G7. Time Resolved Intensity Patterns of the Radiation from Various Regions of a Vacuum Spark Discharge.** H. W. JONES, W. W. MCCORMICK, AND R. A. SAWYER, *Fisk University* (introduced by N. Fuson).—This paper is a report on a quantitative study into the conditions which favor the production of ionic spectra in a high current vacuum spark discharge begun at the University of Michigan in 1952. The spectral light was produced in the spark gap of quarter-inch carbon electrodes by a single oscillatory discharge of a 21.6 $\mu$f condenser bank which could be precharged and then fired at any desired voltage up to 20 kv. By varying the discharge circuit inductance and the condenser voltage, peak currents of 7 to 62 kamp were made available. The instantaneous intensities of four spectral lines of carbon from various regions of the spark gap were obtained by using a photomultiplier and oscilloscope in conjunction with a spectrograph. Plots of the maximum line intensities vs peak discharge current show the excitations is greatest near the electrode that is initially the cathode and that the maximum line intensity does not always occur at the highest value of peak current or the lowest value of circuit inductance.

**G8. Spectral Data from Chemical Releases in the Upper Atmosphere.*** C. DEWEY COOPER, *University of Georgia.*—Spectrographic data were obtained for several twilight chemical releases in the upper atmosphere at Eglin Air Force Base, Florida, during the 1960 summer. The most fruitful of these were those involving the explosive $CsNO_3$ and $NaNO_3$ plus *A*1 releases which were detonated by *RDX*. Three releases between 74 and 83 km provided white clouds which resulted in a very strong scattering of solar radiation. Six releases between 102 and 115 km provided clouds which gave strong resonant lines of sodium and cesium. In addition a band at 4842 A was always observed. Two of the releases gave bands at 4648 A, 5079 A, and 4842 A. These bands have been assigned to the A10 molecule. The presence of this molecule in the releases provides the possibility of obtaining upper atmosphere temperatures from intensity measurements of the rotational lines. Additional weak lines or bands which were observed have been assigned tentatively to atomic oxygen and OH.

* Supported by the Geophysics Directorate, U. S. Air Force Cambridge Research Center.

## High-Energy Physics

### Invited Papers

**K1. Some Preliminary Experimental Studies at the Brookhaven Alternating-Gradient Synchrotron.** LUKE C. L. YUAN, *Brookhaven National Laboratory.*

**K2. Anti-Proton Annihilation Processes.** J. E. LANNUTTI, *Florida State University.*

### Contributed Papers

**K3. Isobar Formation in Neutral Pion Production Reactions at 1100 Mev.*** C. D. GALL AND V. P. KENNEY, *University of Kentucky.*—Bias in the identification of single neutral pion production of the reaction $\pi^-+p \rightarrow p+\pi^-+\pi^0$ has been reduced by requiring observation of a $\pi^0$ decay photon conversion in coincidence with the production reaction. Seventy-six events have been selected on this basis out of approximately 100 000 events recorded in the 10-in. hydrogen bubble chamber at Berkeley. Detailed analysis of these events indicates that (a) pion momentum distributions show significant separation of pions into fast-slow groups above and below the value 325 Mev/c; (b) neutral pions are scattered strongly forward in the cms while the distribution of negative pions is isotropic; (c) the proton and neutral pion are scattered in opposite directions in the cms, while distributions of the other correlation angles are approximately isotropic: (d) the distribution of the values $Q=(E_l^2-p_l^2)^{\frac{1}{2}}-(m_\pi+m_p)$ for the neutral isobar shows peaks at the known excitation values of the $T=J=\frac{3}{2}$ and the $T=\frac{1}{2}$, $J=\frac{3}{2}$ $\pi,p$ scattering resonances. These results are consistent with the view that single neutral pion production proceeds predominantly through the intermediate state $I^0+\pi^0$, with the isobar $I^0$ a mixture of $T=J=\frac{3}{2}$ and $T=\frac{1}{2}$, $J=\frac{3}{2}$ states.

* Research supported in part by the National Science Foundation.

**K4. Secondary Emission of Neutral Pions.*** D. T. KING, *The University of Tennessee.*—Photon spectra found in nuclear emulsions exposed to 3.5 Bev/c negative pions indicate the emission of both fast and slow neutral pions at angles close to the forward direction and neutral pions of intermediate energy at wider angles. These spectral patterns are discernible against a background of slow neutral pions of fractional intensity $20\pm10\%$. The measurements suggest that $80\pm10\%$ of the intense neutral pion emission found in the experiment arises isotropically with relatively low velocities from a fast moving source. Some of the dynamical properties of this source, and its relation to a pion-nucleon rest frame in the target nucleus, will be discussed.

* Supported by the National Science Foundation.

**K5. $\pi^-+p$ Collisions at 3.5 Bev/c.*** R. L. CHILDERS AND D. T. KING, *The University of Tennessee.*—A stack of ten 600-$\mu$ Ilford K5 emulstions was exposed to a 3.5 Bev/c negative pion beam of the Bevatron. The emulsions were mounted on glass and developed by the dry hot stage method in this laboratory. Events which appear to be collisions of pions with free protons have been searched for both by beam track following and by random track following. The tracks from about 80 such events have been identified by grain counting and their momenta measured by multiple scattering. The angles of the tracks also have been measured. The characteristics of the beam, the laboratory system angular and momentum distributions of emergent pions and protons, and the elastic-to-inelastic ratio[1] will be discussed.

* Supported by the National Science Foundation.

[1] W. D. Walker, Phys. Rev. 108, 872 (1957).

**K6.** (Abstract withdrawn.)

**K7. Status of the ICEF Project.*** R. L. FRICKEN,† C. L. DENEY, AND R. W. HUGGETT, *Louisiana State University.*—Properties of nuclear interactions at bombarding energies greater than $10^{12}$ ev are being studied at L.S.U. in connection with our participation in the International Cooperative Emulsion Flight (ICEF) project. There are approximately 45 laboratories in 18 countries collaborating in making these studies on events occurring in an 80-liter emulsion stack exposed near the top of the atmosphere in January, 1960. The first phase of this project is concentrating on problems requiring urgent attention and a large-scale collaboration. The types of measurements made in this first phase will be presented as well as the present status of the project.

* Project supported by the National Science Foundation and the Office of Naval Research, with the L.S.U. laboratory supported in part by the Research Corporation and the Society of Sigma Xi.

† National Science Foundation Graduate Fellow.

## Astronomy, High-Altitude Physics, Biophysics

**L1. Effect of Cobalt-60 Gamma Rays on the Electrophoresis Pattern of Normal Pig Serum.** NEWTON UNDERWOOD AND DAN HIGHTOWER, *North Carolina State College.*—Normal pig serum was exposed to cobalt-60 gamma rays in a gamma cell. A dose rate of approximately $4.2\times10^5$ r/hr was used. Serum samples were exposed to dosages varying from $5\times10^4$ to $5\times10^6$ r, and electrophoretic patterns in agar gel were obtained. A barely detectable change was observed in the pattern at the lowest level of exposure. At the upper level there was little resembalnce to the normal pattern remaining. Intermediate dosages changed the pattern in varying degrees. A correlation between the dose and the observed effect on the electrophoretic pattern will be presented. The electrophoretic motility of the albumin fraction was approximately 4.8-5 cm/hr in normal serum by the techniques utilized. The radiation produced a considerable change in the motility. Several peaks appear to blend at approximately 2.3 cm/hr as the radiation exposure is increased.

**L2. Thermoluminescence Curves, Spectra and Activation Energies of Aromatic Amino Acids, Trypsin, and Spores.** D. R. NELSON AND C. J. WEINBERG, *Oak Ridge National Laboratory* (introduced by R. D. Birkhoff).—Dry, powdered aromatic amino acids, trypsin, and spores were irradiated at 77°K with $Co^{60}$ gamma rays. The glow curves and emission spectra were determined over a temperature range from 77° to 280°K with a series of overlapping bandpass filters. Activation energies were obtained from the glow curves and from a series of initial rise curves. The *L*-phenylalanine glow curve was composed of two major peaks at 120°K and 135°K with activa-

tion energies of 0.28 ev and 0.21 ev, respectively. For both peaks the spectrum consisted of a narrow band at 3125 A and a broad band at 4625 A. The *L*-tyrosine glow curve exhibited a major peak at 120°K with 0.24 ev activation energy and an emission band at 5500 A. The *L*-tryptophane glow curve consisted of two major peaks at 105°K and 135°K. The 135°K peak had an activation energy of 0.20 ev and a spectrum with an emission band at 5825 A. The trypsin glow curve exhibited a gradual rise with a maximum at 120°K and an activation energy of 0.08 ev. The spectrum at 120°K consisted of an emission band at 4625 A. Spores of Baccillus megaterium exhibited a glow curve and spectrum essentially the same as trypsin. The activation energy was 0.16 ev, however, and the glow curve was less intense. Minor glow curve peaks with various spectra were exhibited by all samples.

**L3. Atmospheric Attenuation of Ultraviolet Light.*** V. H. STRAHAN, W. R. STRAHAN, AND C. E. MANDEVILLE, *University of Alabama.*—Ultraviolet attenuation studies have been carried out on ARGMA range 1, Redstone Arsenal, Alabama. Recorded data include temperature, pressure, and relative humidity. Ultraviolet intensities were observed at selected points ranging in distance from 250 to 4400 ft. Photon counter and an arc discharge providing largely radiation at λ2537 A served, respectively, as detector and source. Total linear absorption coefficients were obtained from six complete sets of data. Observed values of the coefficients ranged from 0.934 $km^{-1}$ to 2.67 $km^{-1}$, depending upon the conditions of the measurements. The geometries employed and related corrections will be discussed.

* Assisted in part by the Army Rocket and Guided Missile Agency of the U. S. Army Ordnance Missile Command.

**L4. Zodiacal-Light Intensity Calculations from Light Scattering by Small Spherical Particles.** PERCY E. DREHER, JR., AND RAYMOND T. GRENCHIK, *Louisiana State University.*—To calculate the intensity of the zodiacal light, the full Mie formulas must be used. If natural light of intensity $I_0$ is incident on a sphere, the intensity of the scattered light in any direction is $I=I_0(i_1+i_2)/2k^2r^2$, where $k=2\pi/\lambda$. The computational problem involved is to compute the numbers $i_1$ and $i_2$, where $i_1$ and $i_2$ refer to the intensity of light vibrating perpendicularly and parallel to the plane through the directions of propagation of the incident and scattered beams. A program was written for use of the L.S.U. IBM 650 to compute these numbers. The particles were assumed to be totally reflecting to simplify the equations. A median value of $1\times10^{-3}$ cm was used for the particle radius, and all wavelengths used were in visible range. Some calculations were made for the radius $5\times10^{-4}$ cm. The computed intensity was corrected by a factor of 0.07 for the albedo. In order for $I/I_0$ to correspond to observed values of the zodiacal light ($I=400$ tenth magnitude stars per square degree), the number of particles per $cm^3$ must be made much smaller than that found in the literature.

**L5. Solar Stimulation of the Decameter-Wavelength Radiation from Jupiter.*** ALEX G. SMITH AND T. D. CARR, *University of Florida and Maipu Radioastronomical Observatory of the University of Chile.*—In a preliminary paper[1] the writers reported on an apparent correlation between geomagnetic activity stimulated by solar particles and the long wavelength outbursts of radio-frequency energy on the planet Jupiter. These results were based upon observations made at two frequencies and upon preliminary values of the geomagnetic *A* index. These observations have now been extended to five frequencies, ranging from 10 Mc/sec to 27.6 Mc/sec, and the final values of the *A* index for the 1960 apparition have been used. The analysis suggests that geomagnetic storms tend to be followed about 8 days later by Jupiter radio outbursts. This delay is consistent with the time-of-flight of the particles involved and indicates that the radio noise storms may be triggered by the trapping of solar particles in Jupiter's magnetic field.

* Supported by the National Science Foundation, the U. S. Army Office of Ordnance Research, and the Office of Naval Research.
[1] T. D. Carr, A. G. Smith, and H. Bollhagen, Phys. Rev. Letters 5, 418 (1960).

## *Invited Papers*

**L6. Outer Radiation Belt.** PETER MEYER, *The University of Chicago.*
**L7. Astrophysical Implications of Element Formation.** MARSHAL H. WRUBEL, *Indiana University.*

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**Gall, C. D.**—K3
**Gersch, H. A.**—B3
**Gettys, W. E.**—E8
**Good, W. M.**—A6
**Goodrich, M.**—D6
**Grenchik, R. T.**—L4
**Grenier, C. G.**—E9
**Hales, W. L.**—E4
**Hamilton, J. H.**—D2, D8
**Harris, E. G.**—E5
**Henkel, J. H.**—B6, B8
**Herget, W. F.**—G4, G5
**Hightower, D.**—L1
**Hollander, J. M.**—A7, D1
**Hoover, R. L.**—A11
**Huggett, R. W.**—K7
**Jacks, G. M.**—A9
**Jennings, W. B., Jr.**—E6
**Johnson, C. H.**—D5
**Jones, E. A.**—G3
**Jones, H. W.**—G7
**Jones, W. D.**—G3
**Kendall, H. W.**—E2
**Kenney, V. P.**—K3
**Kilbourn, D. L.**—A3
**King, D. T.**—K4, K5
**King, R. F.**—A6
**Kinslow, M.**—B9
**Kinslow, R.**—B9

Kjellman, J. U.—F5
Koehler, D. R.—F2
Langer, L. M.—D8
Lannutti, J. E.—K2
Lovell, R. J.—G5
Lu, C.—A8
Mallard, W. C.—E6
Mandeville, C. E.—F2, L3
McCormick, W. W.—G7
McEllistrem, M. T.—F4
McGowan, F. K.—F6
Meyer, P.—L6
Murray, R. B.—A1
Neiler, J. H.—F5
Nelson, D. R.—L2
Nielsen, A. H.—G4, G5
Parker, R. A.—D6
Peacock, C. A.—D6
Pershan, P. S.—E12
Pleasonton, F.—D5
Rayburn, L. A.—F1
Reynolds, J. M.—E9
Ritter, R. C.—F6
Roberts, E. M.—E10, E11
Roberts, L. D.—A4, F3
Roberts, T. G.—E4
Robinson, R. L.—F6
Rohrer, R. H.—A2
Rojo, O.—B1
Rose, M. E.—D3
Sawyer, R. A.—G7
Shewell, J. R.—B4
Shields, F. D.—E1
Sieckmann, E. F.—B7
Simmons, L. M., Jr.—B1
Smith, A. G.—L5
Smith, O.—D8
Smith, V. H.—B3
Soper, G. K.—E5
Stelson, P. H.—F6, F8
Stockendal, R.—D8
Strahan, V. H.—L3
Strahan, W. R.—L3
Sybert, J. R.—E9
Temmer, G. M.—F7
Thomson, J. O.—F3
Toth, K. S.—A10
Underwood, N.—L1
Walter, F. J.—A4, A5
Wegener, H.—C1
Weinberg, C. J.—L2
Williams, D.—G2
Wrubel, M. H.—L7
Wyly, L. D.—D7
Yuan, L. C. L.—K1
Zucker, A.—A10

## MINUTES OF THE SPRING MEETING OF THE NEW YORK STATE SECTION HELD AT LEMOYNE COLLEGE, SYRACUSE, NEW YORK, APRIL 14 AND 15, 1961

THE major portion of the program of the 1961 Spring Meeting of the New York State Section at LeMoyne College was devoted to a series of 12 papers under the very timely topic of "A Survey of Amplification by Stimulated Emission of Radiation." As has become customary, these were preceded by papers reviewing the teaching of physics in the area as well as the industrial and academic research being carried out there. A comprehensive summary of the program has been prepared by H. Levinstein for publication in *Physics Today*, and it is expected that several of the authors will submit their papers to *Applied Optics*.

After the banquet on Friday, April 14, the Section and guests were treated to a lecture, beautifully illustrated with color slides, by Father Daniel Linehan, S.J., Department of Geophysics, Boston College on "Recent Expeditions to the Antarctic."

Registration at the meeting was 271. The program and the Minutes of the Executive Committee and of the Business Meeting follow below.

### Program

1. **Welcome,** ROBERT F. GREWEN, *President of LeMoyne College.*

**Brief Sketches of Physics in the Syracuse Area.**

2. **The Physics Curriculum at LeMoyne College.** ROBERT O. BRENNAN.

3. **Teaching and Research in Physics at Syracuse University.** WILLIAM R. FREDRICKSON.

4. **Physics Research at the Carrier Corporation.** JOHN BURLEW.

5. **Physics Research at Electronics Park, General Electric Company.** HARRIS SULLIVAN.

### Symposium

6. **The Basic Atomic Physics Involved in Maser Action—Part 1.** THOMAS R. CARVER, *Princeton University.*

7. **The Basic Atomic Physics Involved in Maser Action—Part 2.** CARROLL O. ALLEY, *University of Rochester.*

8. **Masers for the Microwave Region and Their Application in Spectroscopy and Radioastronomy.** PATRICK THADDEUS, *Radiation Laboratory, Columbia University.*

9. **New Developments in Maser Materials.** HENDRIK J. GERRITSEN, *RCA Laboratories, Princeton.*

10. **A Survey of Methods for Precise Time and Frequency Standards.** PETER L. BENDER, *National Bureau of Standards.*

11. **The Atomic Hydrogen Maser as a Research Tool.** DANIEL KLEPPNER, *Harvard University.*

12. **Solid State Masers for the Optical Region.** D. F. NELSON, *Bell Telephone Laboratories.*

13. **Vapor Phase Masers for the Optical Region.** W. R. BENNETT, JR., *Bell Telephone Laboratories.*

14. **Noise Limitations of Maser Amplifiers.** JOSEPH WEBER, *University of Maryland.*

15. **Low Noise Optical Heterodyne Detection of Laser Generated Light Beams.** GORDON GOULD, *TRG Inc.*

16. **Design and Experimental Demonstration of an Optical Maser.** K. F. TITTEL, F. VON WILLISEN, AND G. WESSEL, *General Electric Company.*

17. **Summary Remarks.** C. O. ALLEY. *University of Rochester.*

## *Minutes of the Executive Committee, New York State Section, April 13, 1961*

*Those present:* T. S. Renzema, D. R. Morey, K. N. Moore, O. Miller, A. F. Turner, M. J. Pryor, H. Levinstein, R. O. Brennan, S.J., F. J. Studer, C. J. Parker, and D. C. Peckham.

D. R. Morey as Chairman-elect expressed the Section's thanks to M. J. Pryor for his work on the Executive Committee from which post he is retiring. Morey then extended the Section's deep gratitude

and sense of obligation to the retiring Secretary-Treasurer, O. E. Miller, for his many years of loyal work in that capacity. (Later, at the Banquet on April 14, plaques were presented to both O. E. Miller and T. S. Renzema for their contributions to the progress of the Section.) D. R. Morey then indicated the special assignments for the newly elected officers, whose names were made public at the Business Meeting on the following day:

K. H. Moore—will arrange the next four programs as Chairman of the Program Committee. Preparations for the Niagara meeting on October 13, 1961 are well under way.

H. Levinstein—will prepare a summary of the Syracuse meeting suitable for publication in *Physics Today*.

R. O. Brennan, S.J.—will publicize the activities of the Section among the parochial colleges of New York State.

C. J. Parker—will review the Section's mailing list with the aim of simplifying and consolidating it for greater effectiveness.

F. J. Studer—will act as back-up official for the proposed N. Y. U. meeting if it materializes.

A. F. Turner—will bring the membership list up-to-date and revise Count Down (with D. R. Morey).

D. C. Peckham and T. S. Renzema—will begin to collect photos, news items and other archival items relevant to the Section's activities in the past. Such a record of the Section's history will be of special interest in connection with the 25th Anniversary Meeting in Schenectady in the Spring of 1963.

New Membership applications were acted upon and 55 were approved.

The meeting which had been called to order at 8:50 p.m. was adjourned at 10:00 p.m.

A. F. TURNER
*Secretary-Treasurer*

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### *Minutes of the Business Meeting, New York State Section, April 14, 1961*

The meeting was called to order by the Chairman, T. Renzema, at 4:50 p.m. Reading of the minutes of the last meeting was dispensed with.

The Treasurer's report was given by the Secretary-Treasurer, O. Miller, and was approved. As of April 13, 1961, the bank balance was $769.06. The Section also has 10 shares of Chemetron Corporation stock valued at $291.25, a gift of D. Morey in 1959. The membership is 463, including 55 new members approved at the Executive Committee Meeting on April 13, 1961.

In the election of officers, 139 ballots were cast. T. Renzema announced the names of the new officers for 1961–1963 as follows:

Chairman: D. R. MOREY, *Eastman Kodak Company*
Vice-Chairman: K. H. MOORE, *Rensselaer Polytechnic Institute*
Secretary-Treasurer: A. F. TURNER, *Bausch & Lomb Incorporated*
Executive Committee: R. O. BRENNAN, *LeMoyne College*; N. A. FINKELSTEIN, *General Dynamics/Electronics*; C. J. PARKER, *Corning Glass Company*; D. C. PECKHAM, *St. Lawrence University*; T. S. RENZEMA, *Clarkson College*; W. V. SMITH, *International Business Machines Corporation*; F. J. STUDER, *General Electric Company*

Y. Beers, who was elected to the Executive Committee, resigned because he is moving out-of-state. The vacancy will be filled later by appointment.

T. S. Renzema voiced official thanks to the Program Chairman of the past two years, D. R. Morey, for his energetic revitalization of the Section's programs as evidenced by the high professional character they now enjoy. Thanks were extended to H. Levinstein for his efforts in behalf of the LeMoyne College program as well as to the members of the local committee:

R. O. Brennan, *Chairman*, LeMoyne College
C. E. McCain, *LeMoyne College*
Mrs. C. E. McCain, *LeMoyne College*
H. Levinstein, *Syracuse University*
J. Stevens, *Carrier Corporation*
J. W. Brouillette, *General Electric Company*
J. Welter, *LeMoyne College*
Mrs. J. Welter, *LeMoyne College*

The local Student Section of the American Institute of Physics was commended for handling the technical details of the LeMoyne Meeting.

A motion was carried to extend the Section's appreciative thanks to the retiring officers for their faithful service, O. E. Miller and M. J. Pryor.

The meeting adjourned at 5:00 p.m.

A. F. TURNER
*Secretary-Treasurer*

## Minutes of the Spring Meeting of the New England Section at Mount Holyoke College, South Hadley, Massachusetts, on April 15, 1961

THE New England Section of the American Physical Society held its annual spring meeting on Saturday, April 15, at Mount Holyoke College, South Hadley, Massachusetts. The program, which attracted a registration of 125 people, consisted of 16 contributed papers, which were divided among three concurrent morning sessions, and an afternoon "Tutorial on Molecular Beam Research."

The "Tutorial" session was the first in a series on various topics which the New England Section of the American Physical Society is planning to organize at each meeting. Eight invited papers were presented in the "Tutorial" under the general title of "Molecular Beam Research at Harvard University."

1. **Introduction.** NORMAN F. RAMSEY
2. **Nuclear Interactions in Acids.** MILTON BAKER
3. **Nuclear Interactions in Hydrocarbons.** CHARLES ANDERSON
4. **Rotational Moments of LiH and LiD.** THOMAS LAWRENCE
5. **Relation of Spin-Rotation Interaction to Magnetic Shielding.** JAMES PINKERTON
6. **Free Radicals.** SUNNEY I. CHAN
7. **The Atomic Hydrogen Maser.** NORVAL FORTSON
8. **Experiments with the Hydrogen Maser.** HOWARD BERG

Response to this initial tutorial session was most favorable; numerous requests were made that this type of program be continued for future meetings.

The New England Section wishes to express appreciation to Mount Holyoke College, and especially to Professor Edward P. Clancy, for the excellent arrangements and accommodations which contributed greatly to the success of the meeting. The Section is also indebted to Professor Norman F. Ramsey and his colleagues for the outstanding success of the tutorial session.

PHILIP J. BRAY, *Secretary-Treasurer*
New England Section

### *Contributed Papers*

**1. Mass Spectrometry Technique.** IMRE FARKASS AND E. J. BARRY, *Ilikon Corporation.*—A discussion is given of the use of mass spectrometers to determine the composition of the residual gases present in an ultra-high vacuum system, to measure extremely small leak rates, and to analyze the nature of gas entering the system through a leak. The placement of the instruments in the system in regard to pressure, presence of contaminants, and location of leaks is discussed. Research results obtained using both a radio-frequency type and a helium-sensitive type mass spectrometer are cited. The inaccuracies which can result from not using the instrument in a proper manner are pointed out. Comparisons are made between our experimental findings and those of other investigators.[1,2]

[1] G. Reich and H. G. Noeller, Z. angew. Phys. 9, 617 (1957).
[2] A. G. Edwards, Brit. J. Appl. Phys. 6, 44 (1955).

**2. Gas Permeability of Solids.** E. J. BARRY AND IMRE FARKASS, *Ilikon Corporation.*—The permeation of gas through solid bulk materials is a complex mechanism involving solution, diffusion, and surface evaporation. A brief discussion is given of the two classical models of the mechanism. A new technique which has been developed involving the use of large metal ultra-high vacuum systems with base pressures in the $10^{-9}$–$10^{-10}$-mm-Hg range is described. This technique allows closer investigation of the phenomenon of gas passage through a solid material and the measurement of extremely low permeability coefficients. A comparison is made between this method and the older systems of such investigators as von Amerongen,[1] Daynes,[2] and Carman.[3] The inaccuracies of the older methods which are eliminated by the new technique are pointed out. The practical application of these measurements for such uses as establishing the suitability of materials for ultra-high vacuum sealants, space vehicle sealants, or pressurized gas containers is pointed out.

[1] G. von Amerongen, J. Appl. Phys. 17, 972 (1942); J. Polymer Sci. 6, 307 (1950).
[2] H. Daynes, Trans. Inst. Rubber Ind. 36, 944 (1940).
[3] P. Carman, *Flow of Gases through Porous Media* (Academic Press, London, 1956).

**3. Coherence Effects in Resonance Fluorescence.** R. L. CAROVILLANO,* *Boston College*, AND M. E. ROSE, *Oak Ridge National Laboratory.*—The crossed-level method of atomic spectroscopy is discussed and the angular distribution formula for both the incoherent and coherent resonance scattering is derived. The form of this distribution function, as given here, explicitly displays the geometric factors depending on radiation propagation vectors. With the application to hydrogen in mind, the distribution function is expressed explicitly for single-electron transitions with external fields possessing axial symmetry. The properties of the distribution are discussed with emphasis on the case of unpolarized radiation. For the case of hydrogen there are two possible applications of major interest. The first concerns the possibility of a precision measurement of the $2p$ fine-structure splitting and, hence, a determination of the fine-structure constant. Explicit results for the shape and other properties of the resonance line with a uniform magnetic field are obtained. The other application is concerned with the possibility of measuring the $2s-2p$ Lamb splitting. This requires an electric field parallel to the magnetic field. Unfortunately, the level crossings which are sensitive to the Lamb splitting cannot radiate sufficiently rapidly while those which do radiate appreciably occur at field strengths which are extremely insensitive to the Lamb splitting.

* Oak Ridge Institute of Nuclear Studies Research Participant, summer 1960.

**4. Variations of the Cosmic Radiation in November, 1960.*** M. A. SHEA AND J. A. LOCKWOOD, *University of New Hampshire.*—The occurrence of several large solar flares between November 12 and 16, 1960 resulted in unusual variations of the cosmic-ray intensity recorded at the earth. Included among these variations were two large increases of ~100% in the nucleonic component of the cosmic radiation as recorded at Mt. Washington and Durham, New Hampshire, and three Forbush-type decreases, the first decrease being superimposed upon the increase occurring November 12. The two increases exhibited different features, and these differences will be discussed in relation to solar phenomena. From a study of worldwide nucleonic intensity data the following results are obtained: (1) the rigidity spectrum can be expressed as $KP^{-n}$ with $n=6$ for both flares; (2) from the dispersion evident for the flare of November 12, where higher rigidity particles

reached a maximum before the lower rigidity particles, it is concluded that there was diffusion of the solar-produced particles; (3) it appears that an albedo effect for particles of ~1 $BV$ was recorded immediately prior to the onset of the Forbush decrease at 1031 on November 13; and (4) the classical impact zone theory as derived by Firor[1] does not apply for the flare on November 15, with evidence being presented for an interplanetary magnetic field.

* Supported by the Geophysical Research Directorate, Air Force Cambridge Research Center, and the National Science Foundation.
[1] J. Firor, Phys. Rev. 94, 1017 (1954).

**5. Cell Theory Equation of the Liquid State for Nonpolar Molecules in Terms of a Variable Coordination Number.** RICHARD A. RHODES, II,* *Brown University.*—The Lennard-Jones and Devonshire cell theory using a 6–12 potential has been modified to include a variable coordination number and has been applied to the equation of state for liquid argon. It is assumed that (1) the coordination number $c$ is a function of specific volume $V$ only, and (2) as the liquid expands, the state of packing passes gradually from face-centered cubic through body-centered cubic to simple cubic and finally to chaos, as the gaseous state is reached. The resulting equation of state is an integro-differential equation which contains the first derivative of $c$ with respect to $V$. To find the $c$-vs-$V$ curve a graphical method of solution is used subject to the boundary conditions of $P$-$V$-$T$ data along the liquid-vapor line and in the triple point and critical point regions. The resulting coordination number varies somewhat with specific volume but remains around 7.5 throughout the liquid range. This does not check well with the direct measurements of coordination number by x-ray diffraction experiments, but is an improvement over the theory using a constant coordination number and also represents a viewpoint which is different from the vacant lattice site theories of Rowlinson and Curtiss and of others.

* Present address: Department of Physics U-46, University of Connecticut, Storrs, Connecticut.

**6. Testing the Degree of Abnormal Behavior of Liquids through Ultrasonic Measurement.** GERALD HOLTON, *Harvard University.*—The effect of pressure on the propagation of ultrasonic waves is now being studied by several investigators. Recent precision measurements of attenuation at high pressures are used to test the validity of models that have been proposed to account for abnormal attenuation in water by structural relaxation mechanisms. Measurements of velocity as a function of pressure and temperature are discussed which aid in deciding by separate criteria the degree of abnormality of the liquid that persists at high pressures.

**7. A New Liquid-Crystal Phase in P-Azoxyanisole.*** JOHN HUBERT MULLER, *Worcester Polytechnic Institute.*—Evidence for the existence of a liquid-crystalline phase in P-Azoxyanisole (hereafter PAA) existing at temperatures below the ordinary nematic state and just above the solid state has been found by simultaneous microscopic observation and temperature measurement with a small thermocouple. When ordinary PAA liquid crystal is allowed to cool in the presence of the solid phase, the temperature as a function of time is found to have two plateaus. Simultaneous microscopic observation indicates the advent of an interface in the liquid at the thermocouple coincident with the first plateau, and preceding the advent of the solid phase which is synchronized with the second, longer plateau. Such highly stable lower liquid-crystal state would explain the prominent supercooling of PAA in the absence of nucleation of crystallization. The more stable lower state possibly requires profound molecular reordering before freezing. It would also explain the slight increase in the splitting of the proton magnetic resonance spectrum observed by Jain, Lee, and Spence[1] as PAA is cooled past the fusion temperature.

* This work was partly done under the National Science Foundation Undergraduate Research Participation Program.
[1] P. L. Jain, J. C. Lee, and R. D. Spence J. Chem. Phys. 23, 878 (1955).

**8. Reactance of Reverse-Biased Thermionic Diode.** J. D. TRIMMER, *University of Massachusetts.*—The reverse-biased solid-state diode has been extensively studied and developed as a voltage-controlled reactance element. It appears, however, that little attention has been given to corresponding possibilities with the thermionic vacuum diode, probably because of the high inherent noise level. This paper will report some effects and experiments illustrating the nonlinear reactance qualities of the thermionic diode.

**9. Derivation of Equilibrium Polarization of Nuclear Spins in a Solid.**—S. P. HEIMS, *Raytheon Company.*—The expected polarization of nuclear spins acted on by an external magnetic field, as well as by the internal fields existing in a solid in thermal equilibrium, is derived. The derivation proceeds by a statistical-mechanical perturbation theory in which the interaction energy between a nucleus and the internal fields is required to be small compared to $kT$. The perturbation expansion gives directly the value of observables; it converges more rapidly than similar expansions for the partition function. General properties of the expansion will be discussed. The perturbations each appear in the form of a trace, so that in evaluation a convenient representation may be chosen for each term; the energy denominator of the second-order perturbation theory for energy levels can be avoided. The well-known effects which systematically appear in this expansion include the Knight shifts, chemical shielding fields, nuclear quadrupolar, pseudo-dipolar, pseudo-quadrupolar, and effective exchange polarization.

**10. Dislocation Climb in Alkali Halide Whisker Crystals.** W. J. SPENCER* AND R. DEAN DRAGSDORF, *Kansas State University.*—Whisker crystals of several alkali halides were grown in a manner similar to that developed by Guylai.[1] The screw component of the axial dislocation in these microcrystals was determined from both their Laue and their Weissenberg diffraction patterns. After annealing at above 500°C for various times, additional Laue photographs indicated a change in the dislocation structure of the crystals. This is interpreted as due to climb of the axial dislocation out of the whisker crystal.

* Present address: Bell Telephone Laboratories, 1600 Osgood Street, North Andover, Massachusetts.
[1] F. Z. Guylai, Z. Physik 138, 317 (1954).

**11. Improvement in the Speed of Photographic Process by the Use of Electric Current Controlled by a Photoconductor.** K. S. LION AND G. F. VANDERSCHMIDT, *Lion Research Corporation.*—The effect of electric fields and currents on photographic emulsions provides new information on the mechanism of the photographic process.[1] This paper describes a method of increasing the speed of photographic emulsions to visible and infrared light by the use of electric current controlled by a photoconducting material.

A sandwich of photoconductor and photographic emulsion is constructed with conductive electrodes on each surface; the conductive electrode adjacent to the photoconductor is transparent. If a voltage is applied across the sandwhich while an image is projected onto the photoconductor, current flows through the photoconductor where the light falls. Over a range of applied voltage the current will cause the formation of a latent image in the emulsion.

Using the method, the speed of red-insensitive emulsions is increased by more than 100 when red and infrared light is used

to make exposures. The result suggests improvements in the technique of infrared photography.

[1] J. F. Hamilton, F. A. Hamm, and L. E. Brady, J. Appl. Phys. 27, 874 (1956); J. F. Hamilton and F. A. Brady, *ibid.* 30, 1893 and 1902 (1959); E. Klein and R. Matejec, Naturwissenschaften 7, 225 (1960); J. Rothstein, Phot. Sci. Eng. 4, 5 (1960); K. S. Lion and G. F. Vanderschmidt, J. Opt. Soc. Am. 45, 1024 (1955).

**12. Resonance Scattering of Bremsstrahlung from Seven Nuclear States.*** E. C. BOOTH, *Boston University*, AND K. A. WRIGHT, *M.I.T.*—Nuclear resonance scattering of bremsstrahlung from a Van de Graaf generator permits the measurement of the mean lifetimes of excited states in stable light nuclei.[1] New results are $Na^{23}$, 2:98 Mev, (46% to ground state), $3.0\times10^{-15}$ g sec; $Si^{29}$, 2.426 Mev, $1.2\times10^{-14}$ g sec; $P^{31}$, 2.232 Mev, $1.8\times10^{-13}$ g sec; $Al^{27}$, 2.98 (3.0?) Mev (22% to ground state), $3.9\times10^{-14}$ g sec; $Cl^{35}$, 1.76 Mev, $3.3\times10^{-13}$ g sec; $Cl^{35}$, 1.22 Mev, $8.3\times10^{-13}$ g sec; $Cu^{63}$, 1.33 Mev, $T>10^{-12}$ sec. "g" includes the statistical factor and angular correlation corrections. Resonance scattering from the 3.01-Mev state of $Cl^{35}$ was also observed, but no lifetime can be assigned since the decay scheme is unknown. The lifetimes are obtained by comparison with other cases measured by the resonance scattering of gamma rays, giving an accuracy of about 30%.

* Supported by the National Science Foundation.
[1] E. C. Booth, Nuclear Phys. 19, 426 (1960).

**13. Range Differences of 10 Mev $C^{12}$ and $He^4$ Ions in $H_2$, $N_2$, and Ar.** F. W. MARTIN AND L. C. NORTHCLIFFE, *Yale University.*—The range differences of carbon and helium ions in the region of 10 to 1 Mev/amu have been measured in various gases. Energies were obtained by magnetic analysis of the ions emerging from the gas, for fixed input energy. The measured range differences are proportional to those for protons in aluminum[1] within 3% of full range—that is,

$$D=-\beta[2.880e^2/(0.6833+\log_{10}\epsilon)]+C,$$

in which $\epsilon$ is in Mev/amu, $D$ is the range difference in mg/cm$^2$, $C$ is a constant not accurately measurable in this experiment, and $\beta$ is found to have the following values: $He^4$ in $H_2$, 0.333; $He^4$ in $N_2$, 0.828; $He^4$ in Ar, 1.11; $C^{12}$ in $H_2$, 0.112; $C^{12}$ in $N_2$, 0.285; $C^{12}$ in Ar, 0.371. The deviations of the data from the above equation will be discussed in terms of the ionization potentials of the gases and the variation of the charge of the carbon ion.

[1] H. Bichsel, Phys. Rev. 112, 1089 (1958).

**14. Emission of Alpha Particles from the System $C^{12}+C^{12}$** G. C. SEAMAN AND A. R. QUINTON,* *Yale University.*—The energy spectra and angular distributions of the alpha particles, arising from the bombardment of a $(C_2H_4)_n$ target by a 123-Mev carbon beam, have been determined with a proportional counter-cesium iodide scintillation counter telescope. The cross section of 1.8 barns for $E_\alpha>5$ Mev indicates that an average of 2.5 alpha particles are emitted from each $C^{12}+C^{12}$ interaction. The cross section drops to 1.3 barns at an incident energy of 85 Mev. A breakup process is suggested by the broad nature of the energy spectra together with the forward peaking of the angular distribution in the center of mass frame. The enforced symmetry about $\theta_{cm}=90°$ makes this reaction study a useful test of the data handling procedures. At extreme forward angles the reaction $H^1(C^{12}, \alpha)B^9$ was observed.

* This work has been supported by the U. S. Atomic Energy Commission.

**15. Energy Calibration of a Spectrometer for Alpha particles and Protons.*** C. R. COTHERN AND A. R. QUINTON, *Yale University.*—A thin target of $(C_2H_4)_n$ when bombarded with a 42-Mev $He^4$ beam provides protons and alpha particles in the ranges 0–27 and 8–42 Mev, respectively. These particles serve to calibrate a proportional counter—cesium iodide particle identifying spectrometer prior to its use in heavy-ion reaction mechanisms studies. The recoil protons arise from the hydrogen content of the target, and their energies, relative to the beam energy, are inferred from the angles of recoil. For $\theta_{lab}<14.5°$ there are the associated alpha particles from the same interaction. The reaction $C^{13}$ $(\alpha,\alpha')C^{13}$ provides four well-separated groups of alpha particles, with comparable intensities at an angle near to 28°. At 160° the $Q=-4.43$ Mev state in $C^{12}$ yields useful numbers of alpha particles whose energy is near to 8 Mev. Since the low-energy region of the spectrometer calibration can be well determined with $Po^{212}$, $Bi^{209}$, and $Pu^{239}$ alpha sources it is possible to measure the beam energy from the 160° data.

* This work was supported by the U. S. Atomic Energy Commission.

**16. Elastic Scattering in the N-N, C-N, and C-C Systems.** A. M. SMITH AND F. E. STEIGERT, *Yale University.*—Differential cross sections have been measured for the elastic scattering reactions $N^{14}$ ($N^{14}$, $N^{14}$) $N^{14}$, $C^{13}$($N^{14}$, $N^{14}$)$C^{13}$, and $C^{13}$($C^{13}$, $C^{13}$)$C^{13}$ to a relative precision of about 4%. Incident energies of nominally 10 Mev/amu were employed, and an angular range was covered from approximately 4° to 24° in the center of mass system. The use of solid-state detectors rendered energy resolution of the order of 0.8% to 1.5% and thereby minimized background contributions. Theoretical cross sections calculated from both the simple diffraction model and the sharp cutoff model were fitted to the experimental data. At relatively large angles the fit obtained from the diffraction model calculation was remarkably good, and interaction radii for the three reactions were calculated to be $6.68\times10^{-13}$ cm, $6.36\times10^{-13}$ cm, and $6.22\times10^{-13}$ cm, respectively. The peak-to-valley ratio of the differential cross section-vs-angle plots fall between those ratios predicted by the unmodified sharp cutoff model and this same model modified by the inclusion of an imaginary nuclear phase shift.

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## MINUTES OF THE SPRING MEETING OF THE OHIO SECTION HELD AT THE UNIVERSITY OF CINCINNATI, APRIL 21–22, 1961

THE regular Spring Meeting of the Ohio Section of the American Physical Society was held in joint session with Section E, Physics and Astronomy, of the Ohio Academy of Science at The University of Cincinnati on Friday and Saturday, April 21–22, 1961.

On Friday morning, members of the Ohio Section participated in the judging of physics projects submitted by high school students of Ohio. This was the final judging of the projects which had been rated superior at earlier district contests sponsored by the Junior Academy of the Ohio Academy of Science

and including projects in all the natural sciences. As usual, the physics projects made up a large fraction of the science projects and numbered 183.

Dr. Paul B. Taylor, Chairman of Section E of the Ohio Academy, presided at the Friday afternoon session and Dr. Albert B. Stewart, Chairman of the Ohio Section, presided at the Saturday morning session. Invited papers were presented by several members of the Departments of Astronomy and Physics of the University of Cincinnati: Dr. Hans Ernst on "The New Cincinnati Cooperative Research Program in Physics and Engineering"; Dr. Isay Balinkin and H. C. Dwight on "Interaction of Light with Light and Colorants"; Dr. Eugene K. Rabe on "Some Problems of Satellite Orbit Computations."

A feature of the Friday afternoon session was a Symposium on "The Teaching of Physics to Students not majoring in Science or Engineering" with Dr. G. E. Owen of Antioch College as moderator and with the following participants: Dr. David Anderson of Oberlin College, Dr. Oliver Loud of Antioch College, and Dr. Philip Macklin of Miami University.

On Saturday morning, a report on "The Programs and Activities of the National Science Foundation" was given by Dr. Conrad E. Ronneberg who was on leave from the Chemistry Department of Denison University to serve as Program Director, Secondary Schools Program, National Science Foundation in Washington, D. C. Dr. G. E. Owen of Antioch College presented a statement in memory of Dr. Leon Smith of Denison University who passed away on January 26, 1961, and had served the Ohio Section as Secretary-Treasurer from 1942 to 1960.

Both sessions included contributed papers for which abstracts appear below.

Officers of the Ohio Section elected to serve for the year 1961–1962 are: Chairman—Dr. John F. Eichelberger, *Mound Laboratory, Monsanto Chemical Company, Miamisburg, Ohio.* Vice-Chairman—Dr. David Griffing, *Miami University, Oxford, Ohio.* Secretary-Treasurer—Dr. W. H. Shaffer, *The Ohio State University, 174 West 18th Avenue, Columbus 10, Ohio.*

W. H. SHAFFER, *Acting Secretary*
Ohio Section

## *Contributed Papers*

**1. Deformation Mechanisms Active During Tensile Tests of Iron Whiskers.** H. WEIK, *University of Cincinnati.*—The phenomenon, that very thin fibers, so-called whiskers, exhibit a tensile strength about one or two orders of magnitudes larger than the tensile strength of bulk material, is believed to be related to the deformation mechanism active during tensile tests. The transition of a regular hexagonal cross section of an iron whisker into an elongated cross section having two right angles, observed after tensile test, can be explained by the assumption that twinning in (112) planes and consecutive flexural glide of the twinned lattice takes place during tensile deformation. By these mechanisms, the original (110) faces of the whisker are converted into (100) faces including two right angles. Multiple occurrence of the same combined deformation and the appearance of slip lines in the deformed cross section are in agreement with the assumed twinning-flexural glide mechanism. The brittle fracture observed in the same whisker is considered a support for the suggested twinning mechanism which is believed to occur with whiskers even at room temperature providing the barrier to the slip.

**2. Applications of a Mass Spectrometer to Research in Biological Systems.** HOWARD E. BALES, *Antioch College.*—The Consolidated Electrodynamics Corporation 21–401 Mass Spectrometer will be described, including special features that adapt the instrument to biological research. Procedures used specifically for nitrogen-fixation studies will be given as well as other applications to general procedures in biological studies.

**3. Methods of Gamma Spectroscopy*: Identification of $Yb^{168}$; and Energy Levels of $Er^{168}$.** G. G. STAEHLE, R. G. WILSON, AND M. L. POOL, *The Ohio State University.*—Enriched $Er^{167}$ was irradiated with helium nuclei to produce $Yb^{168}$. The half-life of this previously unreported activity is nine minutes. The observed radiations were the thulium K x ray, annihilation radiation, and gamma rays of 80.2, 945, 1090, 1275, and 1440 kev, and composite gamma radiation from 635 to 755 kev and 780 to 845 kev. The daughter activity 29-hour $Tm^{168}$, has been studied by means of gamma-gamma coincidence measurements. From these measurements relative gamma-ray intensities, previously reported conversion electron data and from an analysis of the energy levels of other odd-mass nuclei, a level scheme for $Er^{168}$ has been constructed. The 100-channel pulse-height analyzer used in these investigations is compared with other multi-channel analyzers. NaI (Tl) crystals and source-crystal geometries are discussed.

* Supported in part by the Office of Naval Research.

**4. Operation of The Ohio State University Reactor and Its Teaching Potential.** WALTER E. CAREY, CHARLES E. DRYDEN, ALFRED B. GARRETT, CHARLES D. JONES, AND MARION L. POOL, *The Ohio State University.*—A swimming pool type of reactor constructed by the Lockheed Nuclear Products Corporation has been put into operation at the full power of 10 kw. Criticality was achieved with 3.2 Kg of 93% enriched U235 in the core. The salient features of the teaching facility consist of a bulk shielding tank, a 3.9 Kg U235 fission plate, a rabbit, a neutron chopper with a 400-channel time-of-flight analyzer, a neutron-flux trap, radiation cells, two beam ports, a thermal column, etc. Student experiments based on these features will be outlined. Enriched osmium nuclides have been irradiated by the reactor and encouraging results have been achieved.

**5. Effects of Gamma Radiation and Controlled Ambients on Germanium Diodes.** DAVID M. VERRELLI AND WILLIAM L. LEHMANN, *Air Force Institute of Technology.*—Freyer *et al.*[1] have shown that germanium grown junction diodes etched electrolytically in $NH_4OH$ solution exhibit an anomalous current at a critical voltage when under gamma radiation and in a dry oxygen atmosphere. This paper, using a modified CP-4 etch, extended previous work to cover effects of ozone (strongly negative surface charge) as well as dry oxygen (slightly nega-

tive) and water vapor (strongly positive) on the reverse characteristics of germanium diodes both with and without $5.65 \times 10^7$ ergs/gm C-hour Cobalt 60 gamma radiation. The peak was found only in the case of dry oxygen. The results are interpreted as follows: With no gamma radiation, the surface charge is not strong enough to produce an inversion layer with dry oxygen; with gamma radiation, the population of the slow surface states due to dry oxygen is raised sufficiently to produce an inversion layer. At the critical voltage, adsorbed molecules near the junction are desorbed due to the fringing field at the junction, thereby breaking the underlying inversion layer and in turn the current due to the inversion layer. Results appear to be in agreement with the current multiplication mechanism proposed by Statz and deMars.[2]

[1] G. J. Freyer, W. Metscher, and W. L. Lehmann, Bull. Am. Phys. Soc. 5, 465 (1960).
[2] H. Statz and G. A. deMars, Phys. Rev. 111, 169 (1958).

**6. Multiple Coulomb Scattering.** CHOCK IN SIU, *University of Cincinnati.*—The effect of the nuclear form factor on multiple scattering is investigated. Multiple scattering depends sensitively on the nuclear form factor for moderate angles of scattering. Consequently, the theory of multiple scattering provides an additional means of verifying nuclear form factors.

## MINUTES OF THE 1961 SPRING MEETING HELD AT WASHINGTON, D. C., APRIL 24–27, 1961

THE 1961 Washington meeting broke three records: that for the total number of contributed papers at a Washington meeting or at any previous meeting whatsoever, which bounded from a previous 453 to the monumental figure of 537; that for the registration at a Washington meeting, which rose gently from a previous peak of 2082 to the figure 2135, still far below the registration at the New York meetings but well above any value attained anywhere else; that for the attendance at the banquet, which climbed above 500 for the first time and reached to 519. It may seem odd that we do not have to report a new high in the number of simultaneous sessions: this is because for the first time the meeting was spread over no fewer than eight half-days: it has taken us only two years to fill up the fourth day, which in 1960 was provided for the first time! Luckily the Sheraton-Park Hotel has augmented its provision of lecture halls so greatly that it readily accommodates six sessions at a time, and, as for the seventh, we are more than glad to assign it to the National Bureau of Standards both in order to enjoy the excellence of the East Building Lecture Room and to carry on the sixty-year-old tradition of convening at the Bureau. As for the weather it was, as usual, on the warm side. In fact it appears that as these words are written five weeks later, Washington has not again been so warm.

G. T. Seaborg was the after-dinner speaker who was heard by the greatest number of diners ever assembled at one of our banquets: his title was "Some Thoughts on Atomic Energy Research." At the banquet M. L. Goldberger received the (third) Dannie Heineman Prize in Mathematical Physics, with the citation: For his utilization and extension of disperson relations in the physics of strongly interacting elementary particles as examples of outstanding publication in the field of mathematical physics.

W. P. Slichter took his seat on the Council as the first of the two-year nonvoting appointees authorized by the most recent Amendment to the Constitution of the Society.

From the Washington Bulletin I quote the list of members of the Local Committee as provided to me in advance of the meeting: R. D. Huntoon and W. R. Tilley as captains, and D. F. Bleil, R. T. Cook, W. C. Hall, A. I. Mahan, J. H. McMillen, R. B. Roberts, S. F. Singer, and L. Slack. Practice renders perfect, the saying goes: these gentlemen have had a lot of practice and are as nearly perfect as the unexpected tricks of fate (new ones seem to happen every year) will allow. It is impossible for an outsider to tell how the task was distributed: all that I can say is that Tilley and Mrs. Florence Sharkey were constantly and conspicuously busy in the efficient handling of all sorts of situations, and that the guiding hand of Huntoon was evident in the arrangements. We salute them all, and a very special salute is owed by the ladies to those who arranged a most enviable set of privileges for them: the names that we have heard in this office are Mrs. Eugene E. Merkel and Mrs. Alvin G. McNish.

*Elected to Fellowship on April 24, 1961:* Bille C. Carlson, Eugene P. Cooper, Martin H. Edwards, Arthur A. Evett, Joseph R. Feldmeier, Wendell G. Holladay, Sam Legvold, Paul Warren Levy, John S. Luce, Robert L. Mather, William P. Slichter, Rudolph M. Sternheimer, Clayton A. Swenson, and Donald Robertson White.

*Elected to Membership on April 24, 1961:* S. C. Abrahams, Sam F. Adrignola, Daniel Alessandro, Richard R. Allen, Reuben E. Alley, Jr., Margaret Hope Alston, Nissim Almeleh, Antonio Jose Duffles Amarante, Choh-Yi Ang, Maurice Arditi, Andre B. Ashley, Martin H. Bailyn, Samuel I. Baker, Marian Balicki, James R. Barcus, Charles O. Bateman, Lawrence M. Baxt, Herbert B. Bebb, David Kinyoun Benson, Stanley A. Berger, Hugh Wallace Bernard, Leonard Bernstein, Suzanne Berthaut, Meyer H. Birnboim, Loran R. Bittman, Paul E. Blackburn, Patrick Joseph Blewett, Gordon F. Blizard, Jr., Glenn A. Brockman, James C. Browne, Cyrus Anthony Bryant, Rolf D. Buhler, Marvin G. Bures, Robert W. Bussard,

Orison J. Cain, John W. Calkin, Jack R. Canon, Henry S. Caplan, Fernando Cararena, Jr., Anthony J. Cassano, George A. Castellion, Joseph J. Chang, Shan Hsing Chao, Paul M. Chirlian, Armand Cioccio, Charles W. Clapp, Edward A. Clark, J. S. Clark, Norman Clarke, Franklyn Miles Clikeman, George Dewey Cody, Arthur Cohn, Alan R. Cook, Hernando Correa, Bayard R. Corson, Clarence Eugene Corum, William Brooks Cottingham, George W. Crawford, Jeremiah James Cronin, Robert Kyran Curran, James J. Der, Thomas F. Deutsch, Donald Roy Dewhirst, Paul Dinichert, Casimiro Del Rosario, Frederick J. Dominick, Dean C. Douglass, George C. Douglas, Mark W. Dowley, Thomas Henderson Dupree, Jarl A. Elmgren, Charles P. Enz, Reinhard D. Ennulat, Max Epstein, Jay F. Evett, Arthur S. Fairley, Tito Flavio Fazzini, Nikolaus Franz Fiebiger, Edward L. Fink, Carl William Fleischer, Jr., B. L. Fletcher, Ewan W. Fletcher, Neil H. Fox, Peter George Oliver Freund, Louis J. Frisco, O. George Fritz, Jr., Rene B. Galli, Jose D. Garcia, Jr., Dean H. Garrison, Joseph Gaynor, Gioacchino Germana, Meyer Gilden, Ronald Charles Gillis, Philip Goldstein, Friedrich Gonnenwein, Antoine Gourdin, Ronald D. Graft, James Edward Griffin, Paul M. Griffiths, Hubert H. Grimes, Bobby D. Guenther, Ralph L. Gernsey, Ray Gunnink, Russell V. Hanks, Robert E. Harris, Kazi Enamul Haq, Ralph L. Haslund, Owen Walker Hatcher, Jr., Ludwig Henig, Cal C. Herrmann, John R. Hoelzel, Goro Honjo, William W. Hooper, Walter F. Huebner, Herbert Glynn Hughes, Jean Humblet, Douglas Jerome Ingalls, Ronald Boyd Ingalls, Barbara Jackson, Stephen Frank Jacobs, Douglas M. Jamba, Hal Raymond Jeffers, Edward W. Jones, Phillip John Joseph, WooHyung-Kahng, William C. Kaiser, Sebastian Davasia Kalarickal, Wallace Kantor, Alfred J. Kase, Mikio Katayama, Joyce J. Kaufman, Eric Kay, Gabor Kemeny, R. A. Kennedy, Edward Lane Kern, Joseph Mohamad Khalid, Freddy A. Khoury, Young N. Kim, William R. Kineyko, E. David Kipping, Charles W. Klee, Schuyler Kleinhans, Thomas E. Klippert, Donald Avery Kniffen, Richard L. Knuth, Riki Kobayashi, Herwig Kogelnik, Yukitomo Komura, Charles H. Kruger, Jr., Yuri Alekseevich Kruglyak, Nyong D. Kwon, James R. Kymer, Robert F. Landel, S. R. La Paglia, Edward Joseph La Tour, Eugene Arthur Leary, Ileana Beatrix Leavens, Marcel A. R. LeBlanc, Choochon Lee, Chul Chu Lee, J. Lee, Carlton Gorney Lehr, Asa Leifer, Otto Leistiko, Jr., John F. Lennon, Leonard Lionel Levenson, Reginald Frank Lever, Milton J. Linevsky, William T. Link, Max Lipsicas, Sydney Lipton, Ralph A. Logan, Jan T. Lopuszanski, John W. Lotus, S. E. Lovell, John L. Lumley, Marvin L. Luther, D. Lynden-Bell, Ian A. MacFarlane, Malcolm A. MacLeod, Jr., Melecio S. Magno, James R. Manfredi, A. Bernard Marchant, Hanna J. Maria, Velio A. Marsocci, John Bohdan Marushak, J. Max Massey, Jr., Robert G. Mazur, Nelson McAvoy, Arthur T. McCabe, Frederick James McClung, Jr., David W. McDowell, William McIlroy, Philip John McNally, Benjamin Bruce Meckel, Karl L. Merkle, E. A. Meyer, Nasirpal B. Michael, George Sackett Miles, Arthur Miller, G. Frazier Miller, III, Girija Bhushan Mitra, K. L. Moazed, George O. Monnig, Raymond Abraham Moreh, John V. Morgan, Edmond Murad, Kathleen Muray, Mangalam A. Nagarajan, Rodney W. Nichols, Harmon Dennis Nine, Richard Thomas Nowak, Thomas L. Nystrom, Haruo Obayashi, Henry M. O'Bryan, Shigeo Okuda, Jack R. Olson, Ping Hok Ong, Trevor R. Ophel, Edward J. O'Rourke, John M. Osepchuk, Frank J. Padden, Jr., Richard Paolella, Merle R. Paulson, R. Sebastian Pease, Jean Claude Pebay-Peyroula, Frederick G. Penniman, Jr., Harry E. Peters, Laurence E. Peterson, Richard Christian Pilger, Jr., Peter I. Pollak, William Pong, Satya Pal Puri, Yih Pwu, Robert W. Rampolla, Donald A. Ramsay, Devulapalli VGLN Rao, Martin Rayl, Charles W. Ricker, Donald F. Rickert, D. Allen Roberts, John Melville Roberts, Joseph Rosener, Jr., Stanley Ruttenberg, William C. Sauder, Eugen J. Saur, Ralph A. Schaefer, James E. Schirber, Warren A. Schlueter, Larry G. Schneekloth, Paul A. Schumann, David Morris Scott, Lee A. Segel, George M. Seidel, M. A. Short, Paul A. Silberg, Robert J. Silva, Jeremiah N. Silverman, Gabor A. Somorjai, Richard A. Sparks, Herbert H. Spencer, Joseph C. Stachew, R. Antony Stallwood, John J. Stangel, Phillip Henry Steinberg, Dante Stirpe, James Ray Stitts, Thomas M. Straus, Alfred W. Sturr, Koichi Suga, Charles L. Summers, George Susich, David F. Sutter, Lynwood W. Swanson, Hiroshi Tanaca, B. Samuel Tanenbaum, Elsie R. Testa, Bok Yin Tong, Alexander M. Linwin, Henry Van Dyke, Vernon Van Hise, Riek van Wageningen, S. Visvanathan, K. C. Wali, J. Calvin Walker, Robert H. Walker, Marvin E. Wallace, Roger Wright Warren, Joseph S. Wells, Jack Wernick, Eugene A. Wheatley, Jr., David White, Bernard Wieder, Dale Edward Willhite, Russell L. Wilson, John M. Winter, Jr., John H. Woodson, Carl E. Wulfman, Eiso Yamaka, John R. Yoder, Se Won Yoon, Toshio Yoshida, Robert C. Young, and Bice Sechi Zorn.

*Elected to Student Membership on April 24, 1961:* Eric Adler, Richard Ahrenkiel, Charles H. Anderson, E. Walter Anderson, Dan McCay Arnold, Robert Brown Barlow, Jr., Cloyd O. Beasley, Jr., Nicholas A. Beauchamp, J. L. Beeby, Thomas A. Belote, Howard C. Berg, Stuart Brooke Berger, Harold W. Berk, Stuart Bermon, Judith Binstock, Philip E. Bloomfield, Victor A. Bloomfield, Stephen E. Bodner, David C. Bonar, Robert R. Borchers, David G. Boulware, John Judson Bowman, Jeff D. Bronson, Jr., Daniel A. Bronstein, Donald Brownell, Walter V. Budzinski, James J. Burke, Jr., William R. Callahan, Bernard A. Caroli, Hohenemser Christoph, Philip C. Clapp, Harold L. Cohen, James A. Cole, Don M. Cottrell, Richard S. Crandall, James Dehn, Robert E. DeKinder, Jr., Walter Delbianco, John A. Detrio, James Franklin Dillon, Alvin D. Dinhofer, James J. Donaghy, William E. Dorenbusch, Nathaniel John Douglas, Jr., Norman D. Dudey, Andrew J. Dufner, Victor A. Dulock, Martin L. Dwarkin, Kenneth Ray Efferson, Thomas M. Fitzgerald, John N. Fox, Allan David Franklin, Hans R. Fuehrer, Frank Lee Galeener, Christopher Gatrousis, Norman Mathew Gelfand, George Glass, Jacques J. Goldberg, James W. Gordon, Donald E. Groom, Leonard W. Gruenberg, David Gutman, James D. Hall, Darwin J. Harwood, David G. Hill, Lowell H. Holway, Jr., Norman H. Horwitz, John L. Hubisz, Aubrey C. Hudgins, Jr., Henry W. Jackson, Al Sidney Johnston, H. Paul Jolly, Jr., Rex L. Jones, Anthony Thomas Jusick, Ronald C. King, James H. Kinsey, Kenneth F. Kinsey, Janos Kirz, Gilbert C. Knollman, Jack I. Kornfield, Joseph B. Krieger, Joel Kwok, Donald A. Landman, Peter Landshoff, Laurine A. LaPlanche, Martin Harvey La Pointe, Richard Alan La Salle, Thomas R. Lawrence, Robert A. Leacock, Allen M. Lenchek, Joseph D. Lenguadoro, James D. Leslie, Karl R. Lindfors, Eliyahu Litov, David Loebbaka, Albert H. M. Lopez-Escobar, Douglas E. MacLaughlin, John D. Mahony, Sanford Morton Marcus, David George Marker, John R. Marko, George Matassov, George M. McCracken, Roy D. McKenzie, E. A. McLennan, Robert J. McNeal, J. Malcolm McMillan, William L. McMillan, Edmund R. Meskys, Max Gardner Miller, Steven R. Miller, Carlos Alberto Montes de Oca, Charles Bradley Moore, William James Moore, Darrell R. Morrow, Frederick V. Murphy, Jr., James J. Murphy, Richard Stanley Murphy, James Allen Naber, Yasuo Nannichi, Masud Naraghi, Steven S. Newman, Robert M. Nicklow, Donald B. Novotny, Jean M. O'Dell, Robin R. Oder, J. George O'Keefe, John D. Oliver, James C. Owens, Arthur J. Pape, Robert T. Payne, George R. Peacock, Ronald J. Pellar, Leonidas Petrakis, Edward Pollack, Robert E. Pollock, Milton Primer, Andrew Peter Proudian, Sattler Allan Richard, Robert A. Ristinen, James W. Ryan, Fred E. Saalfeld, Ahren J. Sadoff, Harbhajan Singh Sandhu, Richard A. Schroeder, Harris J. Silverstone, George R. Slayton, Adolph E. Smith,

Allan Laslett Smith, Charles F. Smith, Jr., Warren Thomas Sommer, John D. Spangler, Daniel Miller Spitzer, Jr., Daniel Steinberg, Gerard J. Stephenson, Jr., Himan Sternlicht, Ellery W. Stone, Tomoshige Suda, George Clark Summerfield, Mitchel J. Sweig, Edward Amory Sziklas, Raza Ali Tahir-Kheli, Silvestre B. Tejada, Benjamin Tell, Donal D. Thomas, C. C. Ting, Alio M. Title, Steven Julius Török, Robert M. Turnbull, Issacher Unna, Curtis E. Van Beek, Ernst L. Wall, Carl C. Wang, Ching L. Wang, I-Tung Wang, Victor G. Warrinner, Robert A. Wilson, William F. Wolff, David Eldon Wood, Donald Wright, George C. Yang, Costantino S. Yannoni, and Neil Richard Yoder.

## Errata Pertaining to Abstracts B11, BA4, CA1, CA2, N1, SA9, WB10, and ZA7 of the 1961 Washington Meeting

(Series II, Vol. 6, No. 3)

**B11** by Marcel Schmorak, Guy T. Emery, and Gertrude Scharff-Goldhaber. Instead of "$A$ $(12\pm3)\%$ $K$ electron capture branch . . . was found . . ." read "An $(8.9\pm2.3)\%$ $K$ electron capture branch . . . was found . . . ."

**BA4** by S. Geller, H. J. Williams, and R. C. Sherwood. The eleventh line should read "If the 0°K moments of the $Gd^{3+}$ and $Fe^{3+}$ ions are taken as 7.0 and 5.0 $\mu_B$, respectively, the 0°K moment of $Nd^{3+}$ ion appears to be 1.8 $\mu_B$ when $R$=Gd and 1.0 $\mu_B$ when $R=Y$."

**CA1** by Steven Weinberg and **CA2** by S. G. Nilsson. The titles of these two papers should be reversed.

**N1** by R. C. Johnson, T. L. Weatherly, and J. Q. Williams. Starting in line 9, instead of "$B_0=3335.60$ Mc, $eQq=-78.07$ Mc, $D_{JJ}=+0.58$ kc, $D_{JK}=+1.99$ kc," read "$B_0=3335.596$ Mc, $eQq=-77.98$ Mc, $D_{JJ}=0.59$ kc, $D_{JK}=+2.06$ kc." In the last line, instead of "$0.499\pm0.002$ debye, read "$0.50\pm0.01$ debye."

**SA9** by George Schmidt and David Finkelstein. Instead of "If particles trapped . . . end." read "Although there are no solutions in which the magnetic field extends to infinity on the plasma side, it was shown by H. Grad that a solution can be obtained by smoothly piecing a solution with the trivial solution, $B=0$, at a finite point."

**WB10** by O. W. Greenberg. Instead of "but are not in the Borchers class[1] of any $\phi$" read "and are in the Borchers class[1] of their $\phi$."

**ZA7** by I. Kudman and T. Seidel. Delete line: "Inflections are also detected in the absorption data."

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## Minutes of the 1961 Summer Meeting Held in Mexico City, June 22–24, 1961

THE third of the meetings of The American Physical Society held in Mexico, and the second of these to be a joint meeting with the Sociedad Mexicana de Fisica, occurred in Mexico City on Thursday, Friday, and Saturday, June 22–24, 1961. Both of the two previous meetings of the Mexican sequence (we may now correctly speak of a sequence, since there have so far been three and we confidently hope for more) were good; this one was even better, and much the largest of the three. Indeed there were so many (256) contributed papers that it was not feasible to reserve more than a single hour for the Inaugural Session which all members could attend without foregoing simultaneous sessions. This "Inaugural Session" was opened by Doctor Guillermo Torres, Dean of the Faculty of Sciences, representing the Universidad Nacional Autonoma de Mexico and was addressed by the Presidents of the two Societies, by Dr. Manuel Sandoval Vallarta, and by the Secretary of APS. The registration (368 Americans, 126 Mexicans, 13 South Americans, 3 Europeans) outran our brightest expectations, accustomed though we have lately become to "population explosions" in our meetings in the USA. A very large fraction of the "norteamericanos" were visiting Mexico for the first time and fortunate indeed they were to make their first visits under such auspices.

The sessions of Thursday were held in the Ciudad Universitaria, enabling newcomers and "old comers" alike to see this spectacular campus already known to those who came to the 1955 meeting. Those of Friday and Saturday were housed in a building which of all those that this Secretary has ever seen anywhere was the most admirably designed for its purpose, in respect both of its individual lecture rooms and of the situations of these with respect to one another. This wonderful structure was a part of the Centro Medico. If it be allowable to give broad hints as to the future, be it said that such a distribution of time between Centro Medico and Ciudad Universitaria seems a good precedent to follow.

The diversity and versatility of the papers were greater by far than at either of our previous Mexico meetings. For this we may thank the activity of four special committees composed each of members of both Societies, and instructed to recommend invited papers to cosmic-ray physics, experimental nuclear physics, solid-state physics, and theoretical physics, respectively; the activity of our Divisions of Electron Physics and Plasma Physics; and the wide range of interests of the numerous members of each Society who provided contributed papers. Attendance at the sessions was fairly high, and absences could be condoned as being due to the effects

of the charm of Mexico upon those too numerous people from north of the Rio Grande who did not allow time enough to stay before or after the meeting—or before *and* after the meeting. Owing perhaps to the timeless manner of living which IS supposed to prevail "south of the border," a number of the sessions lasted remarkably long. We will not even record the hours at which some of them broke up, lest we set an impossible precedent for our meetings in the USA.

A defect, and the sole defect, of these joint meetings with the "SMF" is that we never know how much we owe nor to whom we owe it. Apart from a sort of token payment made toward the expenses of the banquet, we were guests throughout. We could not have found out more than we did without prying, and there is no assurance that even by prying we should have found out what had been expended for us or by whom it was expended. To our hosts, known or conjectured or unknown, these words are addressed as a general gesture of thanks.

The banquet, attended by 240 people, was held on Friday evening in the Hotel del Prado and was honored by the presence of the Rector of the University, Dr. Ignacio Chavez. For some reason the Presidents of the two Societies delegated the role of master of ceremonies to the Secretary of APS, who accordingly talked much too much in English and Spanish. Far too few of our members paid to the host country the compliment of trying to use its language, and this is the reason why the Secretary of APS refers immodestly to himself. He was successful in inducing the two Presidents—Fernando Alba Andrade and Frederick Seitz—to speak, and also Hugh Dryden; not with others, his apparent neglect to call upon whom may have caused remark. Seldom if ever have we banqueted in such tasteful and beautiful surroundings, except in the same room eleven years ago.

Many of our members from the USA were heard to say that they would like to have more meetings in Mexico, and there is reason to believe that our sister society is not averse from such another meeting nor indeed from a sequence of such meetings. However it is now high time that we in our turn should be hosts in our land at a joint meeting of APS and SMF. Plans are under way for holding such a joint convention at Houston in the late winter of 1963.

KARL K. DARROW, *Secretary*

*Elected to Fellowship on June 22, 1961*: Fay Ajzenberg-Selove, Frederick G. Allen, Douglas S. Billington, Kenneth C. Clark, James H. Crawford, Jr., George Wells Farwell, Willy Haeberli, Isaac Halpern, Boris A. Jacobsohn, Cleland H. Johnson, James M. Lafferty, Gerald W. Ludwig, G. Raymond Satchler, Fred H. Schmidt, Roger A. Strehlow, John S. Toll, and Alfons Weber.

*Elected to Membership on June 22, 1961*: Ansel C. Anderson, Paul R. Akon, Oakes Ames, Robert Dane Barnard, S. Martin Billett, Arthur Boatright, Timothy Booher, Lane K. Branson, Martin J. Casey, Seymour Charton, Ramesh Chaudhry, Glen T. Cheney, Henry Duncan Coghill, Roger W. Cohen, Roger E. Cook, Michael J. Costa, Daniel Cribier, John W. Daiber, William H. Dancy, Jr., Kevin J. Diggins, James J. Dowd, Kenneth Eisenthal, Melvin Epstein, James R. Ewton, Milton Farber, James M. Feldman, D. Raymond Fewer, Edward Robert Flynn, David A. Gandolfo, Jay Gilbert, Sydney Glazer, Reginald Charles Greenwood, Michael Charles Gregg, Joseph Guarnieki, Donald H. A. Hageman, Louis Alton Hall, Robert W. Harris, R. Scott Hebbert, Carl S. Hellmann, James R. Henderson, Walter Herrmann, William F. Hoffmann, Alan K. Hopkins, Robert A. Huggins, Richard M. Humphrey, John Jacovitch, Donald M. Jewart, Joseph R. Jones, Jr., Roger Stanley Jones, William Prichard Jones, Robert S. Kaeser, William A. Kagdis, Mortimer I. Kay, J. D. Keating, Charles M. Kellington, Mohammad Abdul Basir Khan, Jack D. Kingsley, Charles E. Klabunde, Yuzo Kojima, Michael Joseph McCabe, James L. McDonnel, Donald Elmore McLennan, Robert A. Makofski, John L. Margrave, Andrew J. Masley, Joseph Matolich, Jr., Roger M. Miller, Charles Julian Moore, Abraham M. Muhlbaum, Vidya Sagar Nanda, Verne G. Nomady, Edward S. Northam, John A. Palsedge, J. Gavin Park, Ronald G. Parkes, John F. Paulson, Sheila Prasad, Italo Federico Quercia, Leonard L. Reed, John Rheinstein, Robert S. Ricks, Rudy L. Ruggles, Jr., David Richard Sawle, Ernst R. Schneck, Spencer Schuldt, Faison T. Sessoms, Richard L. Sharman, Toshio Shizume, Shmuel Shtrikman, Donald Bellamy Sinclair, Stanley Singer, Alphonse J. Sistino, Clyde W. Skaggs, Paul H. Smith, Charles Darwin Snelling, Bernard Harold Soffer, Donald W. Soyka, Carl A. Stearns, Rogert H. Stowell, Park Haung Su, Levente Szasz, Edward Terner, Brian J. Thompson, Yosbiharu Torizuka, John L. Traub, Victor E. Viola, Jr., Carl-Heinrich von Kenschitzki, William Patrick Walsh, Franklin E. Wawner, Jr., James L. Weaver, Jan J. Went, Richard Harold White, Edward John Whitmore, William T. Wickham, Jr., Suzanne Winsberg, Sumner Paul Wolsky, Roderick G. Wright, Sriramamurti V. Yadavalli, Elmer H. Zeitler, and Glenn W. Zimmer.

*Elected to Student Membership on June 22, 1961*: Edwin W. Albers, Seymour S. Alpert, John D. Antonucci, John Bardwick, III, Vernon D. Barger, J. Lincoln Barr, Lawrence C. Becker, Ronald P. Black, George E. Bodway, Lawrence B. Broadway. Nicholas A. Brown, Richard Ronald Brown, Ngee-Pong Chang, Arthur Noble Chester, Yuen Sam Chinn, David M. Clay, Donald Riley Croley, Jr., Francisco Luis de la Cruz, Robert M. Del Vecchio, Yakov Eckstein, William H. Evans, Richard D. Fink, William G. Firth, Michael Fowler, R. P. Frosch, Faison Peirce Girson, Elizabeth J. Goodman, Edward W. Graham, Evelyn R. Grossberg, Jon E. Haebig, John E. Harriman, Arthur Harris, Peter Hauk, John Covell Hiebert, A. William Hogan, Justin C. Huang, Robert Rowe Hurst, Edwin M. Kellogg, Hugh P. Kelly, Hee J. Kim, Roger L. Kingman, William H. Kirchhoff, Gdalia G. Kleinstein, Allan Laderman, Burton J. McMurtry, James A. Michael, Millard G. Mier, Barry H. Moore, Edward M. Nemeth, Ignacio B. E. Nemirovsky, Peter C. A. Newcomb, Dolores U. Olness, Robert J. Olness, Carl H. Poppe, Maria Elena Porta, John P. Reekstin, Michael P. Remler, Kenneth F. Riley, Richard Francis Roth, William P. Schilling, Richard G. Seyler, Paul John Shaver, Robert W. Sims, Richard G. Smith, James R. Stewart, Bertram L. Strieb, Benjamin E. Tabler, Alan Lee Tanenbaum, John Paul Tarlano, Edward C. Taylor, J. William Tippie, James P. Wade, Jr., Robert K. Wallor, and Richard C. Wayne.

## Errata Pertaining to Abstracts D9, P11, and Q8 of the Mexico City Meeting
(Series II, Vol. 6, No. 4)

**D9** by S. I. Rubinow and Joseph B. Keller. Instead of

$$\mathbf{F}_L=\chi a^3\rho\boldsymbol{\Omega}\times\mathbf{V}[1+0(R)]$$

read

$$\mathbf{F}_L=\pi a^3\rho\boldsymbol{\Omega}\times\mathbf{V}[1+0(R)].$$

**P11** by W. Arthur. In line 5, instead of 1352 read 1333.

**Q8** by D. P. Devor and R. H. Hoskins. In line 17, instead of "between doublets to be about an order of magnitude stronger" read "between doublets to be about an order of magnitude weaker."

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## Minutes of the 1961 International Conference on Photoconductivity Held at Cornell University, Ithaca, New York, August 21, 22, 23, and 24, 1961

THE 1961 International Conference on Photoconductivity met on August 21–24 at Cornell University. The Conference was sponsored by the International Union of Pure and Applied Physics, the American Physical Society, and the Office of Naval Research. This Conference was, in a sense, a successor to the Photoconductivity Conference held in Atlantic City in 1954. However, it differed from the Atlantic City conference in several respects. The 1961 Conference was truly international, with seven nations represented on the Planning Committee. Fully half of the fifty-odd papers on the program reported research conducted outside of the United States. Attendance at the 1961 Conference was open to all workers interested in the field of photoconductivity and appeared to be "self-regulated" at 300. (This regulation, no doubt, was partly due to the exclusion from the Conference of the device aspects of photoconductivity.) The 1961 Conference covered a broader field of interest (with more papers) than the Atlantic City conference. It was also apparent that emphasis has shifted from the lead salts to a wider variety of photoconducting materials.

The Planning Committee, headed by Eli Burstein, and the Program Committee, headed by Albert Rose, succeeded in arranging a comprehensive and balanced program without resorting to parallel sessions. The absence of parallel sessions coupled with the very comfortable facilities for discussion (and coffee) at Cornell's Alice Statler Auditorium provided the maximum opportunity for interaction among the conferees.

Donald Holcomb's Local Committee provided a series of memorable social events, starting with an informal welcoming gathering on Sunday evening and continuing through a cocktail hour on Monday, a good old-fashioned picnic and chicken barbecue on Tuesday afternoon on the shores of Lake Cayuga, and a banquet with good wine and "spontaneous" entertainment on Wednesday evening. Conferees' wives and children (of which there appeared to be a record number) enjoyed a full program of activities and excursions planned by the Ladies Auxiliary of the Local Committee, headed by Mary Sproull and Barbara Krumhansl.

Finally, the Secretary gratefully acknowledges Miss Janice Crisafulli's dedicated service to this Conference.

A. R. Hutson
*Secretary*

## PROGRAMME

### A. Recombination

**A1. Kinetics of Impurity Photoconductivity.** S. M. Ryvkin, *Ioffe Physico-Technical Institute, Leningrad.*—1. Investigating the kinetics of impurity photoconductivity provides a new approach to the problem of determination of the parameters of local levels, not produced when measuring under steady-state conditions. In the case of excitation with rectangular pulses, the photoconduction rise and decay curves reveal a peculiar "asymmetry" connected with the time dependence of the rate of generation. Contrary to the case of intrinsic excitation, the instantaneous relaxation time is determined here not only by capture processes, but by the relaxation of the excitation intensity (i.e., "output") as well. Analyzing the relaxation curves provides a means for the determination of practically all the parameters of the local levels, such as their density, the extent of their occupation by electrons (or holes), the cross section for the photon capture (and hence the impurity absorption coefficient), the recombination coefficient, and the position in the forbidden zone. 2. The experimental investigation of the impurity photoconductivity in CdS, CdTe, and Ge with radiation-induced defects has led to the determination of the parameters of the levels involved in impurity photoconduction. It has been shown that the impurity excitation occurring in the presence of several types of centers (or multiply charged centers) leads to a peculiar "bursting" character of the relaxation curves associated with the charge exchange of the centers. In this case, analyzing the relaxation of the carrier concentration in the zone may be accompanied by a simultaneous measurement of the relaxation of charge density on the impurity levels by means of "long-wave optical probing." 3. The kinetics of the impurity photoelectromagnetic effect in semiconductors has been analyzed.

**A2. Photoconductivity in Semi-Insulating Gallium Arsenide.** B. R. HOLEMAN AND C. HILSUM, *Services Electronics Research Laboratory, Baldock, England.*—The photoconductive (PC) and photoelectromagnetic (PEM) effects have been measured for a number of samples of semi-insulating gallium arsenide (resistivity greater than $10^5$ ohm-cm). The results enable both majority and minority carrier lifetimes to be determined, and some values are given. In the small signal region the lifetimes are found to be only slightly dependent on intensity of illumination, indicating an essentially linear relationship between intensity of illumination and photo signal. For some samples at room temperature the two lifetimes are of the same order of magnitude, indicating that trapping effects are small. A check on these measurements can be obtained in principle from a measurement of photoconductive decay time constants. The spectral dependence of photoconductivity shows two anomalous regions: a rise in quantum efficiency to values greater than unity at short wavelengths, and a tail response extending from the absorption edge to about 1.8 $\mu$. The first of these is tentatively ascribed to surface states, and the second to deep lying levels in the band gap. The presence of deep lying levels is confirmed by measurements of thermally stimulated currents.

**A3. Measurements of Defect States in CdS.** J. FRANKS, *Associated Electrical Industries (Woolwich) Ltd., Harlow, England.*—A method has been developed for determining the ionization energy and temperature dependent capture cross section of trapping states from the half-width and shape of thermal glow and conductivity glow curves. Information on properties of defect levels are also obtained from space charge limited currents and spectral emission studies.

**A4. Spectra and Kinetics of the Photoconductivity in Neutron Bombarded $p$-Type Silicon.** V. S. VAVILOV AND A. F. PLOTNIKOV, *Lebedev Institute of Physics, Moscow.*—New data of the spectral dependence and the kinetics of impurity conduction in neutron-bombarded silicon single crystals are given. Previous optical data of defect levels in silicon[1,2] were obtained for specimens bombarded with large currents ($10^{16}-10^{19}$ n/cm$^2$). The present paper investigates $p$-type silicon containing not more than $5\cdot10^{15}$ cm$^{-3}$ oxygen atoms, bombarded with a neutron current of an average energy of 1 Mev of the order of magnitude $10^{13}$ n/cm$^2$. The spectral distribution of the relative magnitude of photoconductivity exhibits "thresholds" near 4.1 $\mu$, 3.3 $\mu$, and 2.8 $\mu$. The Fermi level, under the experimental conditions (100° abs.), was located at a distance of 0.2–0.3 ev from the valence band; the observed "thresholds" could have been caused by electron transitions to levels $E_v+0.38$ ev and $E_v+0.45$ ev. In the region between 4.1 and 3.6 $\mu$ the photoconductivity curve exhibits an unusual maximum which, in our opinion, is explained by the existence of an absorption band with a long wavelength boundary near 3.8 $\mu$ which probably corresponds to electron transitions to the recombination level $E_v+0.35$ ev. The level in the upper portion of the forbidden band near $E_c-0.16$ ev (its position has been determined previously by other methods[3,4]) was detected in our experiments at 100° abs. as an effective electron trap, i.e., a center with very small hole capture cross sections. Electrons transported to level $E_c-0.16$ ev remained localized on it for several hours. Our experiments indicate that the concentration of the centers which give rise to levels $E_v+0.30$ ev equals $10^{13}$ cm$^{-3}$ under the given experimental conditions. These centers have a double negative charge when an electron is localized on them. The concentration of the centers which give rise to levels $E_v+0.45$ ev amounts to $10^{13}$ centers/cm$^3$. These centers are probably neutral under the same conditions. Experiments show that all centers which introduce levels into the lower portion of the forbidden band are found as a result of bombardment.

[1] H. Y. Fan and A. K. Ramdas, J. Appl. Phys. **30**, 1127 (1959).
[2] V. S. Vavilov, A. F. Plotnikov, and G. V. Zakhvatkin, Zhftt **1**, 976 (1959).
[3] G. Wertheim, J. Appl. Phys. **30**, 1166 (1959).
[4] G. N. Galkin, N. S. Rytova, and V. S. Vavilov, Zhftt **2**, 2025 (1960).

**A5. Recombination Processes in Silicon Doped with In, Ga, and Sb.** YA. E. POKROVSKY AND K. I. SVISTUNOVA,* *Institute of Radio and Electronics, Academy of Sciences, U.S.S.R.*—Transient photoconductivity was studied in silicon doped with In, Ga, and Sb in the temperature range 50–350°K and in a large interval of impurity concentrations. Trapping was observed in $n$-type Si doped with In. Approximate calculation for this case makes it possible to explain quantitatively the dependence of the photoconductivity decay time upon temperature and upon In and equilibrium free charge carrier concentrations. The trapping is shown to be due to capture of holes ionized by In atoms. The holes' capture cross section for In as obtained by transient impurity photoconductivity method is of the order of $10^{-16}$ cm$^{-2}$ and is but weakly temperature-dependent. Electron capture cross section for neutral In atoms is of the order of $10^{-21}$ cm$^2$. The capture of conduction electrons by neutral In atoms is shown to be accompanied by recombination radiation.

* To be read by S. G. Kalashnikov.

**A6. Recombination Properties of Manganese and Gold in Germanium.** V. G. ALEKSEEVA, S. G. KALASHNIKOV, I. V. KARPOVA, AND E. G. LANDSBERG,* *Institute of Radio and Electronics, Academy of Sciences, U.S.S.R.*—Recombination properties of manganese and gold in germanium were studied by PEM and photoconductivity methods in the temperature interval ~350–90°K. The experimental data are in satisfactory agreement with the theory of recombination on multiply charged centers and with the known Mn and Au energy levels. The values of the electron capture cross sections for neutral ($S_n^0$) and singly negative charged ($S_n^-$) Mn and Au ions are obtained, as well as their temperature dependence. Some data on the holes' capture cross sections for doubly negative charged Au ions ($S_p^-$) also are given. The cross sections $S_n^0$ and $S_n^-$ for Au and Mn are but weakly temperature-dependent. This result is typical for a number of acceptor centers in germanium and may be explained theoretically. No significant trapping was observed due to the Au and Mn atoms in $p$-type germanium. In $n$-type germanium there are marked trapping phenomena.

* To be read by S. G. Kalashnikov.

## B. Optical Effects near the Band Edge

**B1. On the Energy Dependence of the Absorption Constant and Photoconductivity Near a Direct Band Gap.** J. J. HOPFIELD, *Bell Telephone Laboratories.*—The absorption of light by a crystal in a spectral region in which direct excitons are observed can best be described as the creation of some (generally complicated) final state by an optical transition through an intermediate exciton state. The energy of the intermediate state determines the exciton absorption line position, but it is the final states which determine the line shape and (since they also describe the final electronic states) are of interest in photoconductivity. It is shown that the exciton absorption line shape often can be expressed in terms of an energy-dependent linewidth, whose exact form depends upon the final states. Direct and indirect exciton absorption with and without phonon cooperation can all be treated simultaneously in the same formalism. The temperature and energy dependence of several different contributions to the exciton linewidth is treated, and its bearing on the energy dependence of photoconductivity discussed. Some speculations on the physical origin of "Uhrbach's rule" will be presented.

**B2. Temperature Dependences of the Fundamental Absorption Tail of KCl and the Absorption due to Bromines in KCl.** KOICHI KOBAYASHI, *University of Tokyo.*—Optical absorption of the fundamental absorption tail of KCl and the absorption due to bromines in KCl were measured between room temperature and 196°C. The measurement of the former was made on a pure KCl crystal with clean fundamental absorption tail which was prepared from potassium bicarbonate and hydrochloric acid. The latter was estimated from the difference between the fundamental absorption tails of pure KCl and KCl with bromine of which concentration was $1.3\times10^{-4}$ in mole fraction. Measured absorption coefficients were corrected by considering the errors due to the finite band width of the spectrometer. The fundamental absorption tail of KCl was found to be represented by the Urbach rule with $\sigma=0.80\pm0.02$ and $h\nu_0=7.76\pm0.10$ ev. The long wavelength side of the absorption due to bromine in KCl could be described by the same rule where $\sigma=0.51\pm0.03$ and $h\nu_0=7.35\pm0.15$ ev.

**B3. Experiment on Exciton Absorption in $PbI_2$.** I. IMAI, *University of Tokyo* (to be presented by T. Muto).—We have investigated experimentally exciton absorption in thin films with thickness of 500 A of $PbI_2$ in the temperature range from room temperature down to 37°K (a few samples at 4.2°K). Any trace of hydrogen-like series structure of exciton absorption spectra could not be observed in the vicinity of the first fundamental absorption in contradistinction to the observed result by Nikitine and his co-workers. Then the detailed study of the first fundamental absorption line in $PbI_2$ was made in order to clarify its characteristics, i.e., temperature dependencies of both peak frequency, half-width, and tail part on the longer wavelength side. The oscillator strength estimated from the area covered by the absorption band becomes 0.001, and Urbach's law seems to be valid with $\sigma=1.4$ in the tail part. A simple, Born-cycle calculation yields 2.3 ev in comparison with the observed value of 2.52 ev. All these evidences seem to indicate that an exciton (associated with the fundamental absorption) in $PbI_2$ behaves as in those silver halides and alkali halides.

**B4. Fine Structure of the Spectral Curves of Photoconductivity and Luminescence Excitation and Its Correlation to Exciton Absorption Spectrum.** E. F. GROSS AND B. V. NOVIKOV, *Physico Technical Institute, Leningrad.*—In recent years both Soviet and foreign physicists have been intensively investigating the exciton structure of the fundamental absorption edge in semiconductor crystals at low temperatures. It was observed that substances having such a structure are fairly strong photoconductors. This fact leads to the conclusion that there is a correlation between the exciton absorption lines and the shape of the photoconductivity curve. Crystals with well-known structures of the absorption edge (CdS, $Cu_2O$, $HgI_2$, $PbI_2$, and GaSe) were chosen for investigation. A fine structure of the spectral curves of photoconductivity, corresponding to exciton absorption lines, was discovered in all the investigated crystals at low temperatures. Its properties in a CdS single crystal were studied in detail. It turned out that either the maxima (1st type of crystal) or the minima (2nd type of crystal) of the photocurrent curves could correspond to the exciton absorption lines. By means of proper treatment crystals can be converted from one type into another and vice versa. The distinction between crystals of different types is retained also at room temperature. Such a phenomenon also is observed in crystals of $HgI_2$, $PbI_2$, and GaSe. The coincidence of photocurrent and absorption maxima is considered as a consequence of exciton participation in giving rise to photocurrent. Possible mechanisms of exciton participation in creating charge carriers are discussed. On the spectral curve of luminescence excitation of CdS crystals at low temperatures, a fine structure related to the exciton spectrum, also is observed. Either maxima or minima on the excitation spectral curve coincide with the exciton absorption lines.

**B5. Fine Structure in the Absorption Edge of the Silver Halides.** FREDERICK C. BROWN AND T. MASUMI, *University of Illinois.*—The results of new optical absorption measurements on pure AgCl and AgBr will be reported and compared with the wavelength dependence of photoconductivity in these materials. Detailed structure consisting of a low-level absorption tail and several shoulders has been found at 4.2°K. The data will be analyzed in terms of indirect and direct optical transitions together with a plausible band structure and vibration spectrum.

**B6. Band Edge Emission Properties of CdTe.*** R. E. HALSTED, M. LORENZ, AND B. SEGALL, *General Electric Research Laboratory.*—The near band edge emission spectra of single crystal CdTe at ~20°K consists of sets of "lines" separated by the longitudinal optical phonon energy $0.0213\pm0.002$ ev.[1] The specific sets observed vary with impurity content and stoichiometry. The widths ( $<kT$ in some cases) and relative intensity of successive satellite lines in a set are larger for the more deeply bound recombination centers which are more strongly coupled to the lattice. Informative comparisons can be made with analogous spectra in other II–VI compounds. Tentative interpretations of the various sets in terms of (a) direct exciton recombination, (b) electron hole recombination from an immobile four-particle complex,[2] and (c) transitions involving states of isolated defects and pairs of neighboring[3] defects are being considered. The emission spectra further provide information regarding etching, annealing, and oxidation characteristics of CdTe. The relative ease of crystal preparation and control of conductivity type suggest that CdTe investigations can prove most useful in correlating the electrical and optical properties of II–VI compounds.

* Partially supported by the Air Research and Development Command, U. S. Air Force.

[1] R. E. Halsted, D. T. F. Marple, M. Lorenz, and B. Segall, Bull. Am. Phys. Soc. 6, 148 (1961).

[2] J. R. Haynes, Phys. Rev. Letters 4, 361 (1960).

[3] J. S. Prener and F. E. Williams, J. Phys. Chem. Solids 8, 461 (1959).

## BA. Band-to-Band Photoconductivity

**BA1. Unusual Photoconductive Effects.** T. S. MOSS, *Royal Aircraft Est., England.*—Conventional photoconductive effects occur when radiation excites electrons from bound states to states where they can move freely through the crystal. The increase in conductivity is thus due to an *increase* in the number of mobile electrons, their mobility being the same as those present before illumination. There exists a second class of phenomena where increases of conductivity result from transitions which excite carriers (already mobile) from one state to another of higher mobility—the total number of carriers remaining unchanged. If the mobility change is large—as can easily be the case—the effect will be appreciable if the densities of excited carriers ($\Delta n$) are comparable with those in normal photoconductivity. However, since $\Delta n=Q\tau$, this depends directly on the lifetime in the high mobility state. The determination of $\tau$ may well be the most important outcome of this type of experiment. Some particular effects which will be discussed are (1) vertical transitions between degenerate valence bands, (2) phonon assisted transitions between energy extrema in different regions of $k$ space, (3) transitions between magnetic Landau levels, (4) transitions within the conduction band continuum and energy dependence of mobility, (5) effects in metals, (6) effects in superconductors.

## C. Field Effects

**C1. Field and Current Distributions in the Pre-Breakdown Region in CdS Monocrystals.** K. W. BÖER, *Humboldt Univer*

*sity, Berlin.*—The field and current distribution in CdS will be described by a new electro-optical method. Well-known inhomogeneities, e.g., barrier layers and current channels, will be confirmed. New effects, such as plasma-like inhomogeneities and kinetical effects in the breakdown region, will be discussed. The mechanism of the development of these effects will be given.

**C2. High Electric Fields in CdS.** RICHARD WILLIAMS, *RCA Laboratories.*—A technique has been developed for measuring and studying high electric fields in CdS crystals. Fields are produced by a transparent blocking electrode in direct contact with a conducting crystal. Direct current field-effect experiments have been used to measure the magnitude of the electric field and its distribution within the crystal. Electro-optic effects occur in fields greater than $10^5$ v/cm, and dielectric breakdown occurs in fields greater than $10^6$ v/cm. The main electro-optic effect is a shift of the optical band edge to longer wavelengths with increasing fields. This is believed to be due to the photon-assisted tunneling process discussed theoretically by Franz and Keldysch. Results are in approximate quantitative agreement with theory. Dielectric breakdown field strengths have been measured in a variety of crystals. The mechanism of dielectric breakdown has been studied by several kinds of experiments including measurement of pre-breakdown currents as a function of field and study of the behavior of optically injected carriers as breakdown proceeds. Results are compared with theoretical treatments of dielectric breakdown.

**C3. Saturation of Photocurrents in Strong Electrical Fields.** F. STÖCKMANN, *Technische Hochschule, Karlsruhe.*—Earlier investigations show that all photoconductors without impurities can be divided into four groups with respect to photocurrent saturation. This grouping is equivalent to the division of semiconductors with respect to the injection of charge carriers: only minority carriers, only majority carriers, and the two carrier types for impurity or intrinsic conductors. After simple substitutions, the relationships derived for idealized photoconductors are valid also for photoconductors with impurities. Generally valid expressions are derived for the four groups for saturation currents and for the field strengths required for saturation with the limitation, however, that the equilibrium concentrations change only slightly due to illumination. The relationships derived for the steady state are applicable to calculations of time-dependent photocurrents when the excitation function is expanded in its Fourier spectrum. Light-intensity variations for every spectral component $\omega$ are derived when all magnitudes denoting time $\tau$ in the simple time-dependent relations are replaced with a relaxation term $\tau/(1+i\omega\tau)$. The recombination lifetime of minority carriers is the only characteristic time, in addition to the dielectric relaxation time, derived for idealized photoconductors; for photoconductors with recombination centers and traps, five different characteristic times, on which photocurrents are dependent, are derived for the two carrier types.

**C4. Recombination of Hot Carriers in Germanium—Theoretical.** E. M. CONWELL, *General Telephone and Electronics Laboratories, Inc.*—Studying the recombination of hot carriers makes it possible to separate the dependence of recombination rate on speed of the carriers from other dependences that change with temperature. The observation that the bulk recombination rate is increased by applying high fields[1] indicates that the average product of speed and capture cross section is larger for hot carriers. To obtain from the data the dependence of the cross section on speed, the theory of the kinetics of recombination at a trap level has been extended to cover the case of hot carriers, and integration of the resulting differential equations is being carried out. It also has been shown theoretically that increase of the average carrier energy should increase the diffusion rate of excess carriers in Ge, and thus decrease surface lifetime; this is in agreement with the experimental data.[1] Data on samples with lifetimes determined by the diffusion rate are being used to calculate the average energy of the hot carriers as a function of electric field intensity.

[1] See abstract C5.

**C5. Recombination of Hot Carriers in Germanium—Experimental.** J. ZUCKER,* *General Telephone and Electronics Laboratories, Inc.*—The recombination of excess hot carriers in germanium has been investigated by measuring the change in photoconductivity caused by exciting samples with 2.85-kMc microwaves up to peak fields of $10^4$ v/cm. Microwave rather than dc pulse excitation was used to prevent the sweepout of excess carriers. The microwave frequency was within the range for which the velocity distribution in germanium can follow the field variations.[1] By applying a small dc sweep field to illuminated samples, the changes in photoconductivity could be obtained from oscillograms of the sample current immediately following the microwave pulse. It was found in some cases that application of the microwave field caused changes in sample current following the pulse even though no excess carriers had been introduced by light or contacts; data on such samples were not used. Samples whose lifetimes were determined by diffusion to the surface, recombination at surface centers, and recombination at copper impurities in the bulk were investigated in this manner. In all these samples a decreased photoconductivity was observed immediately following the microwave pulse, indicating enhanced recombination in the high field.

* Portion of a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree, Department of Physics, New York University, New York, New York.

[1] J. Zucker, V. Fowler, and E. Conwell (submitted to J. Appl. Phys.).

**C6. Negative Resistance and High Electric Field Capture Rates in Semiconductors.** B. K. RIDLEY AND T. B. WATKINS, *Mullard Research Laboratories, Salfords, England.*—The variation with electric field of the rate of capture of electrons and holes by charged impurity centres in semiconductors is discussed. With attractive centers it is shown that ionization can occur as the field is increased due to the resultant decrease of capture rate. The capture rate of repulsive centers can increase with field with the result that deionization occurs. In the latter case negative resistance effects become possible, and the conditions under which it may be expected are considered, both when the carriers are thermally generated and when they are optically generated. Such negative resistance effects will be frequency-dependent since the trapping time constant governs the process of deionization. The effect of thermal fluctuations in charge density of frequency of the order of the trapping frequency when the crystal is in the negative resistance region is discussed. Some experimental results on suitably doped germanium will be presented.

**C7. Recombination Processes in Far Infrared Photoconductors.** GERALD S. PICUS, *Hughes Research Laboratories.*—The conductivity, Hall effect, photoresponse, and noise in germanium-doped with Zn, Cu, and In have been measured at 4.2°K as a function of applied electric field and incident background photon flux in an effort to better understand the free carrier generation and recombination processes. The $I$–$V$ characteristic shows a high field breakdown independent of photon flux coincident with that observed in 4.2°K dark. At intermediate values of electric field, the current varies as $I=I_0(\exp V/V_0-1)$ where $I_0$ is proportional to the incident photon flux and $V_0$ is approximately 0.4 of the critical breakdown voltage. For low fields, the sample is ohmic with conductivity proportional to incident photon flux. The equivalent short circuit signal current $i_s$ observed in response to a constant

additional radiation input (small compared to the background flux) is proportional to the bias current $I$ in the low and intermediate field regions and falls off at high fields. The fields at which the ratio $i_s/I$ begins to decrease is believed to be an accurate indication of the onset of impact ionization generation of free carriers. A qualitative model explaining the results in terms of the variation with electric field of the sticking probability of a carrier in the excited states of a giant trap[1] has been developed.

[1] M. Lax, Phys. Rev. 119, 1502 (1960).

**C8. Photoconductivity Research in Cu-Ge Filaments.** H. D. ADAMS, W. J. BEYEN, AND R. L. PETRITZ, *Texas Instruments, Inc.*—Photoconductivity and electrical phenomena associated with the 0.04-ev copper acceptor level in germanium have been examined. Experimental data giving the dependence of photoresponse $(\Delta P/P)_S$ fluctuations in carrier density due to generation and recombination processes $(\Delta P/P)_N$ and current on the electric field across the filament are presented. The effect on the above data of varying copper concentrations and the amount of ambient radiation incident on the Cu-Ge filament are given. Both ac and dc effective quantum yields have been measured and are dependent upon the electric field across the filament. This phenomenon has been previously observed by Burstein, Picus, and Jacobs in Zn-Ge, but no explanation has been reported. A mechanism which accounts for the increase in effective quantum yield with electric field is proposed.

## CA. Photo-Hall Effects

**CA1. Photo-Hall Effects in Photoconductors.*** R. H. BUBE, H. E. MACDONALD, AND J. BLANC, *RCA Laboratories.*—Measurements of Hall mobility as a function of light excitation intensity at room temperature have shown a strong dependence of mobility on intensity in single crystals of CdS, CdSe, GaAs, and InP. There are two types of effect: (1) a single-step increase in mobility $\mu$ between two limiting values reached at very low and very high intensities, the total change in $\mu$ being not more than a factor of 2 or 3; and (2) a very rapid decrease in $\mu$ for low light intensities, the total change in $\mu$ being as large as a factor of 25. The nature of the effect is not appreciably dependent on the location of test electrodes on the crystal or on the wavelength of illumination used. Effects of the first type show the functional dependence on carrier density expected of a change in scattering resulting from a change in occupancy of scattering centers. The energy of such centers, determined from mobility data, agrees with the energy of trapping centers detected by thermally stimulated current measurements. When the density of centers obtained from the thermally stimulated current data is used in a point-defect scattering analysis, anomalously large cross sections of the order of $10^{-11}$ to $10^{-10}$ cm$^2$ are obtained. Photo-Hall measurements also indicate free hole conductivity in infrared quenching experiments in CdS.

* The research reported in this paper was sponsored in part by the Air Research and Development Command, U. S. Air Force.

**CA2. Hall Measurements in CdSe Sintered Layers.** A. FOWLER, *IBM Research Center.*—Measurements of the Hall mobility and conductivity of photoconducting CdSe sintered layers have been made over the range of temperatures from liquid nitrogen to room temperature as a function of illumination using an ac modification of the Van der Pauw[1] technique. The mobility was found to vary as the $\frac{1}{16}$ power of illumination in a region where the conductivity varied as the $\frac{1}{4}$ power of the illumination. No plateaus of the type reported by Bube and MacDonald[2] were observed. A variation of mobility has been observed as a function of the wavelength of the exciting radiation when the conductance of the sample is maintained constant, which indicates that the carriers do not diffuse appreciably away from the illuminated surface.

[1] L. J. Van der Pauw, Philips Research Repts. 13, 1 (1958).
[2] R. H. Bube and H. E. MacDonald, Phys. Rev. 121, 473 (1961).

## D. Contact Effects

**D1. Role of Injecting Contacts in Photoconductors.** MURRAY A. LAMPERT, *RCA Laboratories.*—It is usually assumed that the only role of the "ohmic," i.e., injecting, contacts is that of supporting Ohm's law currents through the photoconductor. In actual fact the injecting contact plays a key role in limiting the available gain ($G$)-bandwidth ($1/\tau_0$) product of the photoconductor, through the agency of space-charge which is either injected and volume-distributed[1] or spatially localized near the potential minimum at the contact.[2] $G/\tau_0$ has a limiting value $M/\tau_r$, where $\tau_r$ is the dielectric relaxation time under operating conditions and $M$ is a dimensionless quantity determined by either the volume-distributed[1] or contact-localized space charge.[2] Where the negative contact is injecting for electrons and the positive contact injecting for holes, two-carrier current flow in the insulator is supplied by the contacts. Double injection and photoconductivity are closely related in that the characteristics of both phenomena are governed by the same recombination centers. Double injection has been analyzed for an idealized insulator with a single set of recombination centers completely filled in thermal equilibrium. Outstanding results are (a) a threshold voltage for the double injection, in disagreement with Broser[3] and (b) a negative resistance associated with a hole lifetime which increases with injection level.

[1] A. Rose and M. A. Lambert, Phys. Rev. 113, 1227 (1959).
[2] M. A. Lambert and A. Rose, Phys. Rev. 113, 1236 (1959).
[3] I. Broser and R. Broser-Warminsky, J. Phys. Chem. Solids 6, 386 (1958).

**D2. Electron Injection and Extraction in CdS Single Crystals.** W. RUPPEL, *Laboratories RCA Ltd., Zurich.*—Depending on the nature of the contact, the application of a voltage to an insulator can cause either the injection or the extraction of carriers. In the case of electron injection the field in the crystal increases from cathode to anode, and the total crystal charge is negative. Extraction of electron shifts the maximum field toward the cathode and leaves the crystal positively charged. The determination of the sign of the total crystal charge therefore presents an unambiguous criterion for the distinction between net injection and net extraction. The transition from electron injection to extraction by the measurement of the total crystal charge was observed for CdS crystals with pressed indium electrodes as a function of applied voltage and light intensity. At small applied voltages injection of electrons is found, while at high voltages extraction predominates. The transition from electron injection to extraction, determined by the change from negative to positive total crystal charge, also is observed with increasing light intensity at constant applied voltage. The conclusion drawn from the charge measurements is confirmed by the form of the current-voltage-characteristics at various light intensities.

**D3. Contact Influence on the Photoconductivity of Lead Oxide.** L. HEYNE, *Philips Research Laboratories, Eindhoven.*—Continuous primary photocurrents can be observed in PbO layers obtained by vacuum evaporation and sandwiched between Ag or Ag-$SnO_2$ contacts. When the dark conductance which is determined by the deviation from stoichiometry is strongly $p$ type, the following characteristics occur: saturating photocurrent-voltage dependence at unity quantum yield, linear photocurrent-intensity dependence, and localization of the photosensitivity near the anode. This indicates blocking contacts for holes. Layers made $n$ type by a treatment at low oxygen pressure show a gain factor exceeding unity, no saturation, and high dark current. The photosensitivity is not

localized to a particular electrode. Thus the same type of contacts can replenish conduction electrons in this case. Further information is obtained from "electrical" glow curves. The voltage dependence of currents generated by electrons when they are released from traps is markedly different from that occurring with holes. This makes it possible to determine the charge-carrier sign during the glow experiment. The presence of a blocking layer is demonstrated by a modified thermo-stimulated current experiment. Transition from blocking into replenishing action of the contacts also for holes occurs when the PbO is doped with $n$ and $p$ type impurities together. The photocurrent-light intensity characteristic becomes superlinear, indicating an illumination dependent replenishment.

## II–VI Compounds

**DA1. Low-Temperature Photoconductivity and Luminescence of Group II–VI Compounds.** I. BROSER AND R. BROSER, *Institut für Elektronenmikroskopie am Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin-Dahlem.*—Several optical and electrical properties of group II–VI compounds appear only, or can be better studied, in the region of very low temperatures. These phenomena comprise the very marked decrease of photoconductivity between the temperature of liquid air and the temperature of liquid helium, the existence of impurity band conductivity, the action of additional infrared radiation upon photoconductivity and luminescence, the behavior of antistokes and edge emission, and the appearance of sharp "exciton" lines in excitation and emission spectra. A survey will be given about measurements on these subjects which have been done in our laboratories with single crystals of ZnS, CdS, ZnSe, and CdSe. Photoconductivity and luminescence have been investigated at temperatures between 1° and 80°K, in most cases comparing both properties at the same specimen. The results lead to some new ideas on energy states of lattice defects and impurities which determine the mobilities of charge carriers, the mechanism of energy transport, and the recombination processes.

**DA2. Structure of Photoconductivity Spectra near the Fundamental Absorption Edge of CdS.** HIROJI MITSUHASHI, *Japan Broadcasting Corporation* (NHK), *Setagayaku, Tokyo.*—The spectral structures of photoconductivity on grown single crystals of pure CdS were investigated using polarized incident light at low temperature of ca. 81°K. From the experimental results, the structures are classified into two groups: one is attributed to the photoconductivity due to excitons which occurs in the shorter wavelength range ($\lambda < 4870$ A) and the other to that from some imperfections or impurities involved in the crystal, which appears on the longer wavelength side. Exciton photoconductivity is consistent with the exciton spectra, identified by Thomas and Hopfield.[1] The irregular structures of longer wavelength side vary from one sample to another. Peaks of imperfection photoconductivity tend to shift to the longer wavelength with increasing field strength, though there was no recognizable shift for those of the exciton photoconductivity. The trend of shorter lifetime was observed for the exciton photoconductivity, in principal accord with the interpretation of the difference of lifetimes between the volume and surface excitations.[2] On the basis of the experimental data, an assignment was made for the center responsible to the imperfection photoconductivity after the Lambe-Klick model.[3]

[1] D. G. Thomas and J. J. Hopfield, Phys. Rev. 116, 573 (1959).
[2] R. H. Bube, Phys. Rev. 101, 1668 (1956).
[3] J. Lambe and C. C. Klick, Phys. Rev. 98, 909 (1955).

**DA3. Photoconductivity of ZnO as a Surface Phenomenon.** G. HEILAND, *Universitaet Erlangen, Germany.*—Up to now photoconductivity of ZnO has not been reported as a volume effect in single crystals. The most prominent feature of the surface photoconductivity (single crystals and evaporated layers) is the increase through several orders of magnitude with the surface conductivity in the dark. The explanation for this connection has changed since the Atlantic City Conference. At present it seems probable that photo- and dark conductivity are connected by means of traps for the majority carriers (electrons), whereas the influence of light intensity is determined by trapping of minority carriers. This model is based on measurements of field effect and photoconductivity at the same crystals. Some conclusions concerning the storage of electrons and holes at the surface are drawn. Lifetimes and trap densities are estimated. Surface conductivity and therewith photoconductivity decrease through orders of magnitude by the adsorption of oxygen. The course of this adsorption was followed not only by conductance measurements, but also simultaneously by an optical method using multiple reflections. Photodesorption of oxygen together with photoconduction usually happens. This was studied, using a small mass spectrometer. Only atomic oxygen was found desorbing.

**DA4. Use of Paramagnetic Resonance to Detect Optical Processes in Photoconductors.** REUBEN S. TITLE, *IBM Research Center.*—In photoconductivity the light-induced transfer of charge from one impurity or defect site in the lattice to another is a common process. It is in fact while the charge is free that it contributes to the photocurrent. As a result, the valence of the sites involved in the process will change by one. In principle this valence change should be observable using paramagnetic resonance absorption techniques because at each site we are going from a state with an even number of electrons to an odd number or vice versa. The use of paramagnetic resonance to detect light induced charge transfer will be illustrated by several experiments carried out on II–VI compounds doped with various impurities. In addition to the observed valence change, charge association between pairs of impurities has been detected. The resonance technique is useful in that it isolates a single microscopic process occurring during photoconductivity and hence is a definite aid in setting up a model for the photoconductive process. It also will be shown how the apparatus used to detect paramagnetic resonance can be used to measure microwave photoconductivity, obviating the necessity of electroding the sample.

## E. Infrared Photoconductors

**E1. Impurity Photoconductivity in $n$-Type InSb.** E. H. PUTLEY, *R.R.E. Malvern, England.*—Photoconductivity has been observed in sufficiently pure $n$-type InSb when illuminated by radiation of wavelengths between 0.1 and 8.6 mm. The time constant of this effect has been found to be of the order of (but probably less than) 1 μsec. The electrical properties (Hall effect, magnetoresistance effect, and hot electron effects) have been studied in some detail. Both the photoconductive and electrical properties depend very strongly upon the presence of a magnetic field. This dependence and the relation between the photoconductive and electrical properties will be discussed.

**E2. Photoconductivity of Deep Acceptor Impurities in InSb.*** W. ENGELER,† H. LEVINSTEIN, AND C. STANNARD, JR., *Syracuse University.*—Copper, silver, gold, and nickel recently have been shown to introduce deep acceptor energy levels into InSb.[1] Extrinsic photoconductive response due to these impurities has been observed. The spectral response of this photoconductivity shows several long wavelength cutoff edges. The position of these edges is interpreted in terms of the two energy levels of the Ib column elements. Since the positions of the upper ionization levels could not be uniquely determined from the variation of the Hall constant with temperature, the

data for the long wavelength cutoff of the photoconductivity is used to determine the energies of these levels. Values of 0.039 ev and 0.066 ev for the upper levels of Ag and Au, respectively, have been determined.

* Sponsored by Air Research and Development Command, U. S. Air Force.
† Present address: General Electric Research Laboratory, Schenectady, New York.
[1] W. Engeler and H. Levinstein, Bull. Am. Phys. Soc. 6, 156 (1961).

**E3. Temperature Dependence of a Capture Cross Section for Holes in Gold-Doped Germanium.** G. RUPPRECHT, *Raytheon Company.*—The capture cross section of the 0.145-ev acceptor level of gold in germanium has been measured by pulsed field effect technique and was found to be $3\times10^{-13}$ cm², independent of the gold concentration (measured between $10^{13}$ and $10^{16}$ cm$^{-3}$). Extension of these measurements over a wider range of temperatures, from 50° to 100°K, yields the temperature behavior of the capture cross section which follows approximately a $T^{-4}$ dependence. This is equivalent to a constant recombination rate. Allowing for possible experimental errors, it has been assured that the temperature dependence of the cross section is less than $T^{-1}$. This is a surprising result in the light of M. Lax's theory of "giant traps" which should be perfectly applicable in this case. Lax's theory of giant traps predicts a temperature dependence of the cross section with $T^{-4}$ for an attractive center which has been confirmed by data of S. H. Koenig for shallow impurities in germanium between 4° and 9°K. The disagreement of experiment and theory in the case of a deep-lying level in a different temperature range reopens the question for a capture mechanism which yields an absolute value of the cross section of the order of $10^{-13}$ cm² and at the same time shows a weak temperature dependence. The requirements for a theory of the capture of majority carriers drawn from this experiment will be discussed. The gold-doped germanium is not the only example of a weak temperature dependence of the capture cross section. Data on nickel- and manganese-doped germanium, though not yet as accurate at present, show the same behavior as the gold acceptor level.

**E4. Carrier Lifetimes in *n*-Type Gold-Doped Germanium.** R. L. WILLIAMS,* *Canadian Armament Research and Development Establishment.*—Minority and majority carrier lifetimes in *n*-type gold-doped germanium have been evaluated by means of the combined photoconductive and photoelectromagnetic effects. The room-temperature capture cross section of the upper gold level for electrons is evaluated to be $1.0(\pm0.3)\times10^{-16}$ cm² and for holes $1.5(\pm1.0)\times10^{-13}$ cm². These values agree with the order of magnitude values found by Johnston and Levinstein. Between 150° and 60°K an exponential temperature dependence is found for the electron capture cross section with an activation energy of 0.1 ev. Between room temperatures and 400°K, surface recombination effects are important, but the PC/PEM ratio method permits the evaluation of the now nearly equal electron and hole lifetime. Equations are derived for the electron carrier concentration temperature dependence, with partial compensation of the gold level 0.20 ev from the conduction band. The expression is used to evaluate the donor and acceptor concentrations: $Nd=4.7\times10^{15}$/cm³ and $Na=2.9\times10^{15}$/cm³. In analyzing the data, a mobility ratio of 1.2 at 370°K is required to make the observed data agree with the calculations.

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**E5. Low-Temperature Electron Trapping Lifetimes and Extrinsic Photoconductivity in *n*-Type Silicon Doped with Shallow Impurities.*** R. S. LEVITT AND A. HONIG, *Syracuse University.*—The trapping lifetimes of conduction electrons photoexcited from shallow impurities have been measured in the liquid helium temperature range for samples of *n*-type silicon whose donor and compensating acceptor concentrations vary from $\sim10^{13}$ to $\sim10^{15}$ impurities/cm³. A steady-state method was employed, in which the lifetime $t_L$ is equal to $n_e\tau_i/N_D^0$. $n_e$ is the conduction electron concentration which is determined from low-temperature photo-Hall measurements, and $N_D^0/\tau_i$ is the electron generation rate. The neutral donor concentration $N_D^0$ is measured by the Hall effect, and $\tau_i$, the lifetime against photoionization of a neutral donor, is measured directly by an electron spin resonance technique.[1] The trapping lifetimes are independent of temperature between 4.2° and 1.2°K and are inversely proportional to the compensating acceptor concentration. This latter was determined using a recently developed combined infrared radiation and spin resonance method.[2] The result for phosphorus donors is a trapping cross section of about $7\times10^{-12}$ cm². This value as well as the temperature and concentration dependences is in qualitative agreement with the giant trap theory of Lax.[3] The mobility of electrons photoexcited with $\sim2$-$\mu$ radiation considerably exceeds the mobility of electrons photoexcited with 8- to 25-$\mu$ radiation. This suggests the possibility of excitation to another band by the 2-$\mu$ radiation, as is also suggested by the free carrier absorption peak[4] found in *n*-type silicon.

* Supported in part by the U. S. Air Force Office of Scientific Research.
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## EA. Uncommon Materials

**EA1. Studies of Photoconductivity in Iodine Single Crystals.** A. MANY, M. SIMHONY, S. Z. WEISZ, AND J. LEVINSON, *The Hebrew University, Jerusalem.*—Transient and steady-state photoconductivity measurements on single crystals of iodine are reported. The kinetics of carrier recombination and trapping were studied using short light pulses. From transit-time measurements of photoexcited carriers in a sandwich-type configuration, the drift mobility of holes at room temperature was determined as 0.8 cm²/v sec, this value being practically temperature-independent in the range investigated. The photosignal associated with the electrons is considerably smaller than that for holes. To eliminate contact effects, blocking electrodes were employed. Owing to the short relaxation times associated with the dark conductivity ($\sim10^{-8}$ ohm$^{-1}$ cm$^{-1}$), pulse techniques were used: the light pulse was flashed shortly after the onset of the applied field pulse, before polarization could be set up in the sample. The spectral response of steady-state photoconductivity was found to consist of two main sensitivity bands. The first band is centered around 0.45 $\mu$ and exhibits several peaks. The second band is peaked at 0.9 $\mu$ and is about two orders of magnitude weaker. The response to polarized light is anisotropic, the first band being favored by the $E$ vector parallel to the $a$ axis of the crystal and the second band by $E$ parallel to the $c$ axis. The questions of quantum yield and production mechanism of carriers are discussed.

**EA2. Optical Absorption and Photoconductivity in Germanium Selenide.*** C. R. KANNEWURF AND R. J. CASHMAN, *Northwestern University.*—Optical absorption was investigated in extremely thin single crystal specimens of GeSe. Absorption data at 300°K cover a wavelength range of 1.20 to 0.45 $\mu$ with the absorption coefficient changing from 30 to $1.2\times10^5$ cm$^{-1}$. An analysis of the absorption edge for direct and indirect transitions is described. In the high absorption region a direct transition photon energy dependence of $(h\nu-E_g)^{\frac{1}{2}}$ with $E_g=1.53$ ev was shown to give a good fit to the data over a considerably greater energy range than was found for $(h\nu-E_g)^{\frac{1}{2}}$. The spectral response curve for an evaporated film

type photoconductive layer was obtained for the same wavelength range. This curve shows two bands of responsivity with the threshold energies corresponding closely to the energy gap values that were determined for the direct and indirect band transitions.

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## F. Ionic Crystals

**F1. A Comprehensive Description of a Simple Photoconductive Phosphor.** FRITZ LÜTY, *II. Physikalisches Institut der Technischen Hochschule, Stuttgart.*—Alkali-halide crystals containing anion vacancies, which are either empty ($\alpha$ center) or filled with one ($F$ center) or two electrons ($F'$ center), represent a convenient system for studying electron processes: with only two types of donors ($F$ and $F'$ centers) and two types of traps ($\alpha$ and $F$ centers), optical irradiation into the donor absorption bands causes electron transitions which can be quantitatively observed by combined measurements of absorption, photoconductivity, fluorescence, and phosphorescence. This was done in dependence on temperature, electric field, and impurity concentrations for KCl. By a systematic variation of the three types of point imperfections, the ratio of capture cross sections of $\alpha$ and $F$ centers for electrons was evaluated in dependence on temperature. These measurements allow a quantitative understanding of the results on $F$–$F'$ and $F'$–$F$ conversion, $F$ fluorescence, and $F$ phosphorescence. One obtains a model of a photoconductive phosphor whose electron transitions can be described by equations of second-order kinetics without any unknown values. The application of high electric fields (several $10^5$ v/cm) on this system causes marked changes in the electron transitions by field emission out of states lying closely under the conduction band. These changes in $F$–$F'$ and $F'$–$F$ conversion and all luminescence properties—which were measured in dependence on field strength—confirm the mechanism of electron freeing and trapping processes proposed for the system.

**F2. Photoconductivity in Zone-Refined KCl.** H. KANZAKI, T. NINOMIYA, AND K. KIDO, *University of Tokyo.*—Single crystalline ingots of KCl containing divalent impurity ions of less than $1\times10^{14}$ cm$^{-3}$ have been obtained by successive application of chemical purification, vacuum distillation, and zone refining. Photoconductivity experiments utilizing electrons excited from $F$ centers have been performed in order to clarify the nature of electron traps in these highly purified crystals. Various amounts of $F$ centers were introduced either by additive coloration or by irradiation of penetrating x ray at room temperature. Photoconductivity has been measured by using monochromatic light pulses and an electrometer. The amount of induced charge per light pulse is at most $10^{-14}$ to $10^{-13}$ coulombs cm$^{-2}$. Dependence of $\eta w_0$ (quantum yield times unit range) has been studied as a function of $F$-center concentrations ($3\times10^{15}$ to $5\times10^{16}$ cm$^{-3}$) and also of temperatures (78° to 220°K) in order to discuss the nature of electron traps. Schubweg of electrons at 78°K is determined primarily by concentration of $F$ centers down to $3\times10^{15}$ cm$^{-3}$ in the case of annealed good crystals. The value of $\eta w_0$ at 78°K is nearly $1\times10^{-8}$ cm$^2$/v in annealed crystals containing $3\times10^{15}$ $F$ centers cm$^{-3}$. Photo-response at 78°K is very sensitive to density of dislocations, and a value of $\eta w_0$ as low as $10^{-11}$ cm$^2$/v has been found in x-rayed crystals with high density of dislocations.

**F3. Pulse and Steady Photoconductivities of Colored Alkali Halides.** MASAMI ONUKI AND HIROSHI OHKURA, *Osaka City University.*—Measurements of pulse and steady photoconductivities have been made on additively colored KBr and KCl in an attempt to investigate various kinds of electron trap in the colored alkali halides. The space charge polarization effect, which makes it difficult to detect the true photoconductivity of the specimen, was studied. The conditions to hold a specimen free from the space charge effect were found by using pulse and ac methods. The temperature dependence of pulse photocurrent was measured by varying the duration of the pulsive $F$-light illumination. The time constants of current decay after switching-off of illumination were also observed. The ac photoconductive response under steady $F$-light illumination vs illumination level was measured at various temperatures. The exponent in the relation, (current) $\propto$ (light intensity)$^p$, was found to vary from 1.0 at low temperatures to about 0.5 at room temperature. Applying the theory of the trapping kinetics to the above results, the properties of the following electron-traps are discussed in detail: (1) $F$ centers, (2) vacant $F$ centers (or negative ion vacancies), and (3) unknown centers.

**F4. Hole Photoconductivity in KBr Crystals Containing $Br_3^-$ Molecule Ions.*** CHARLES J. DELBECQ AND PHILIP H. YUSTER, *Argonne National Laboratory.*—After x-ray irradiation at liquid nitrogen temperature, holes are trapped by forming $Br_3^-$ molecule ions in KBr containing one of the impurities $Ag^+$, $Tl^+$, $Ag^+$, or $NO_3^-$. It has been found that the impurities act as efficient electron traps and increase the rate of production of $Br_2^-$. An investigation of the optical and paramagnetic resonance spectra of these crystals leads to an identification of the optical absorption bands of the $Br_2^-$ molecule ion. The $Br_2^-$ molecule ions are oriented along $\langle 110\rangle$ directions in the crystal and have two principal absorption bands at 385 m$\mu$ and 750 m$\mu$, both of which show anisotropic properties. Irradiation into either one of these bands with $[0\bar{1}1]$ polarized light causes a redistribution of the ions among the six $\langle 110\rangle$ directions in the crystal so that the population in $[011]$ is considerably enhanced. Because of this change in population, the absorption as measured with $[0\bar{1}1]$ light will decrease, and the absorption as measured with $[011]$ light will increase. Photoconductivity has been observed upon bleaching with light of 750 m$\mu$ wavelength. The bleaching light used was polarized along either $[0\bar{1}1]$ or $[011]$. Since continued bleaching at 750 m$\mu$ with $[0\bar{1}1]$ light causes a decrease in the absorption to $[0\bar{1}1]$ light, the observed photoconductivity decreases. If the plane of polarization of the bleaching light is rotated to $[011]$, the photoconductivity rises and then decays to an equilibrium value. These changes in photoconductivity have been correlated with changes produced in the optical absorption spectra of $Br_2^-$.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

**F5. Photoconductivity in RbI and KI.*** Y. NAKAI AND K. TEEGARDEN,† *University of Rochester.*—A threshold for intrinsic photoconductivity has been observed in RbI and KI at −77° and −190°C. These experiments were carried out with an electrode arrangement quite different from that employed previously by Teegarden and in a considerably cleaner vacuum.[1] Photoconductivity occurs on the short wavelength side of the first exciton band in the region of the shoulder previously ascribed to the onset of band to band transitions.[2] Photoconductivity also can occur on the long wavelength side of the first exciton peak when $F$ centers or other kinds of electron surplus centers, formed by irradiation with ultraviolet light, are present in the crystals.

* Work supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
† Alfred P. Sloan Foundation Research Fellow.
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**F6. Photoconductivity of Some Alkali-Halide Crystals in the Fundamental Absorption Range.** GORO KUWABARA AND KIYOSHI AOYAGI, *University of Tokyo.*—The photoconductivity of KI, KBr, and KCl for the light in the fundamental

absorption range was measured at room temperature. The photocurrent was detected at the low energy tail of the first absorption band showing the peak at around the wavelength corresponding to the absorption coefficient of a few $cm^{-1}$ for each crystal. The current drops sharply at the first absorption peak and again rises gradually as the photon energy is increased. The structures found in the spectral sensitivity curves above the higher energy tail of the first absorption peak are almost ascribed to the change of reflection loss. It is supposed that the photons in the first peak of the exciton band absorbed by the undisturbed part of the crystals do not contribute to the photoconductivity and that above the higher energy tail of the first peak free carriers are created with the nearly uniform quantum efficiency.

## FA. Organic Materials

**FA1. Photoconductivity in Organic Materials.** J. KOMMANDEUR, *Union Carbide Corporation.*—In general, it is very difficult to define a "band gap" in organic materials. The ultraviolet spectrum of the solid is almost identical to that of the molecules in the vapor phase. Therefore, light absorption is essentially determined by the single molecules. Thus, no relation between thermal and optical band gap is to be expected or found. Phenomenologically, anthracene can be used for an illustration of most of the properties encountered. Surface currents and bulk currents have been observed and separated experimentally. Under inhomogeneous illumination, space charge effects, the Dember effect, and many other related phenomena have been detected. The photoresponse is closely related to the absorption spectrum and depends critically on the geometrical arrangement. The material is exceedingly sensitive to neutron irradiation. The high impedance of the material precludes measurements of the Hall or photoelectromagnetic effect, but recently Kepler[1] has measured the hole and electron mobilities by a pulsed photoconductivity technique. He finds that the mobilities are of the order of 1 $cm^2$/v-sec and anisotropic. Calculations and experiments by LeBlanc[2] have confirmed this result. The magnitude of the photocurrents and their spectral sensitivity can be changed markedly by absorption of electron acceptors, or donors, on the surface of the crystals.[3] This leads to the conclusion, already inferred from other work, that most of the charge carriers are generated in the surface layer.

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[2] O. LeBlanc, J. Chem. Phys. **33**, 626 (1960).
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## G. Photoemission and Photoconductivity

**G1. Photoconductivity and the External Photoelectric Effect in PbS.*** ABBOTT SMITH AND DAVID DUTTON, *University of Rochester.*—We have measured the absolute spectral dependence of photoconductivity and external photoemission in the wavelength range $\lambda = 584$ to 3000 A for PbS films and for natural galena crystals. We had previously reported[1] evidence that "electron multiplication"[2] occurred in PbS layers with an apparent incident-photon threshold energy $h\nu_t = 2$ ev. The present investigation has established that (a) for $h\nu > 8$ ev, external photoyields are much larger than internal yields and rise to 20 to 30% at the shortest wavelengths; (b) the observed photoelectric threshold $\phi_t \sim 5$ ev (for galena crystal surfaces cleaved in vacuum) or $\sim 6$ ev (for chemically deposited PbS layers similar to commercial photoconductive cells); (c) from observations of the yields and energy distribution of external photoelectrons, one can infer, at least qualitatively, the dependence on the incident photon energy $h\nu$ of the cross section for scattering of electrons (by the "multiplication" effect or otherwise). For a substance (such as PbS) in which a photoelectron must have an energy appreciably greater than the band gap $E_G$ in order to escape from the crystal, scattering processes, especially "multiplication," normally are expected to reduce the obtainable external yield.[3,4] Our observations of the energy distribution of the external electrons imply a scattering cross section which is not a monotonically rising function of $h\nu$(incident) but has instead one or more maxima and minima—in particular, one rather sharp maximum at $h\nu = 10.2$ ev. These observations are consistent with the observed high yields.

* Research supported by National Aeronautics and Space Administration (Goddard Space Flight Center) and by Office of Scientific Research, U. S. Air Force.
[1] A. Smith and D. Dutton, J. Opt. Soc. Am. **48**, 1007 (1958).
[2] See also S. Koc, Czech. J. Phys. **7**, 91 (1957); J. Tauc, J. Chem. Phys. Solids **8**, 219 (1959); and V. S. Vavilov *ibid.*, p. 223.
[3] L. Apker, E. Taft, and J. Dickey, J. Opt. Soc. Am. **43**, 78 (1953).
[4] E. Taft, H. Phillip, and L. Apker, Phys. Rev. **110**, 876 (1958).

**G2. Production of Pairs in Semiconductors by Low-Energy Electrons.** W. E. SPICER, *RCA Laboratories.*—By using the velocity distribution of photoelectrons, the probability of pair production[1] has been studied in a number of alkali-antimonide semiconductors[2] as a function of electron energy. For $Na_2KSb$, $K_2Sb$, and $Rb_2Sb$, the threshold energy for pair production was found to be about three times the band-gap energy. For $Cs_2Sb$, the threshold energy may be equal to the band-gap energy.[1,2] Through a detailed analysis of the velocity distribution, it is possible to measure the mean free path for pair production as a function of electron energy. This varies from about 100 A for electrons with energies a few tenths of an electron volt above the threshold energy to about 10 A for electrons with energies several electron volts in excess of the threshold energy.

[1] L. Apker, E. Taft, and J. Dickey, J. Opt. Soc. Am. **43**, 78 (1953); E. Taft and H. Phillip, Phys. Rev. **115**, 1583 (1959).
[2] W. E. Spicer, Phys. Rev. **112**, 114 (1958); J. Appl. Phys. **31**, 2077 (1960).

## GA. Noise

**GA1. Some Topics in the Fluctuations of Photo-Processes in Solids.** RONALD E. BURGESS, *University of British Columbia.*—When photons with energy in excess of the ionization energy are absorbed in a photoconductor, the fluctuations associated with the photocarriers are enhanced because of the finite thermalization time of the energetic carriers and the probability of secondary ionization. This is compared with the case of a strong electric field in which carrier heating and impact ionization are sustained causes of enhanced noise. The possibility of electron distributions with effectively negative temperatures is discussed in connection with schemes of photon amplification and detection using stimulated emission in semiconductors. The fluctuations of photon and carrier numbers are shown to correspond to variances which are simply related to the effective temperatures of the respective populations. When photons are incident on an imperfect absorber, it is customary to invoke binomial statistics in considering the effect on the fluctuations in the number of absorbed photons. This is shown to be incorrect, and the appropriate expression is derived and shown to be compatible with the energy fluctuation theorem. A general analysis of multiplication processes is developed and applied to situations where the fate of a photon or an electron is determined by arbitrary statistical functions.

**GA2. A Unified Statistical Approach to Recombination-Generation Noise and Lifetimes in Semiconductors.** D. A. EVANS AND P. T. LANDSBERG, *University College, Cardiff.*—This paper offers a unified discussion of equilibrium recombination-generation noise in semiconductors and of its relation (in general, as well as in specific cases) to the steady-state and transient lifetimes. It extends many existing results, and an attempt is made to cover situations where certain types of Auger (electron collision) processes, as well as one-electron transitions, contribute to the noise. The cases of degenerate

bands, and of centers each able to trap one or more electrons, are included. The new general results are, however, on the whole less complicated in form than their already known special cases. This is in part due to the fact that the equations are here expressed in a form which is symmetrical in bands and traps, so that there is no need to distinguish between them in the formal part of the theory.

**GA3. Generation-Recombination Noise and Capture Cross Sections in Germanium.** L. J. NEURINGER AND W. BERNARD, *Raytheon Company.*—Generation-recombination noise in semiconductors arises from the modulation of the conductivity by the random thermal fluctuation of charge carriers between the valence (or conduction) band and the impurity levels. With certain impurities such as gold in germanium, it is possible to have two interacting levels simultaneously contributing to the generation-recombination process and consequently to the noise. We have studied samples of gold-doped germanium in which the Fermi level lies midway between the 0.041-ev donor level and the 0.145-ev acceptor level, such that the noise spectrum of a given sample simultaneously exhibits relaxation times characteristic of both levels. A straightforward theory has been developed capable of accounting for all of the observed noise in interacting two-level systems of this type. Estimates of the capture cross sections of free holes by the 0.041-ev donor level and the 0.145-ev acceptor level in $p$-type gold-doped germanium have been obtained from measurements of the generation-recombination noise spectrum in the range $10^4$–$10^7$ cps. Good agreement was obtained between theory and experiment, using values for the total cross sections of $\sigma_A = 1.55\times10^{-13}$ cm$^2$, $\sigma_D = 3.75\times10^{-18}$ cm$^2$. These values are in qualitative agreement with other independent measurements.

**GA4. Generation-Recombination Noise in Various Photoconductive Semiconductors (Ge-Ni, Ge-Mn, InSb, Te).** F. M. KLAASSEN, K. M. VAN VLIET, J. R. FASSETT, AND D. PAI, *Free University of Amsterdam, Netherlands, and University of Minnesota.*—Generation-recombination noise refers to carrier density fluctuations caused by spontaneous fluctuations in generation, recombination, and trapping rates, including that part which is due to photon noise of the (background) radiation field. Recently extensive studies have been made on materials containing various trapping levels, double acceptors, etc. Several photoconductive semiconductors will be briefly reported here; viz., nickel- and manganese-doped germanium, indium antimonide, and tellurium. *Nickel-doped germanium.* When the Fermi level is near the lowest acceptor level, the relaxation time is related to $\sigma_p^-$, the capture cross sections of singly ionized acceptors for holes. At higher temperatures, it is shown that the upper acceptor levels act as recombination centers (hole traps). The noise equivalent power is $6\times10^{-10}$ w for $h\nu = 0.3$ ev and $T = 150$°K. *Manganese-doped germanium.* Noise was measured both in the dark and under infrared irradiation. *InSb. G–R* noise was observed in $p$-type samples in the specific temperature range when the Hall coefficient is large and negative, before it changes sign. The minimum noise equivalent power is of the order of $10^{-9}$ w. *Tellurium.* Two kinds of spectra have been observed, viz., of the diffusion type, showing a high frequency $1/f^1$ behavior and the normal bulk $g$-$r$ spectra.

**GA5. Noise Power Spectrum of Single-Crystal Indium Antimonide.** D. W. GOODWIN, *Royal Radar Establishment, Great Malvern, England.*—The noise power spectrum of indium antimonide at 77°K has been measured for specimens having extrinsic hole concentrations between $10^{12}$ and $10^{16}$/cc. For frequencies greater than 1 Kc/s there is evidence for shot noise. Carrier lifetime determinations from these measurements suggest majority carrier photoconduction in agreement with lifetime determination by photocurrent decay methods. At low frequencies the noise power is proportional to the inverse of the square of the frequency and is proportional to the extrinsic carrier concentration. Evidence is given which shows that the noise power spectrum is independent of surface potential. The most likely solution to the noise problem is to be found in the "queuing mechanism."

## POST-DEADLINE PAPERS

**Ultrasonic Investigation of Photoconductivity in CdS.** A. R. HUTSON, *Bell Telephone Laboratories, Inc.*—The variation of ultrasonic attenuation in a piezoelectric photoconductor due to a dc electric field in the direction of wave propagation[1] may be used to study details of the photoconductive process. In particular, the drift mobility of electrons in photoconductive CdS has been measured in this way.[1] It also is possible to measure the relative contributions of electrons and holes to the photoconductivity and the drift mobilities of each species in this type of experiment. Carrier trapping, where it is fast compared with the ultrasonic frequency, will lower the observed drift mobilities. Carrier heating due to the drift field may be observed through the effect of enhanced diffusion on ultrasonic attenuation vs drift field curves.

[1] A. R. Hutson, J. H. McFee, and D. L. White, Phys. Rev. Letters **7**, 237 (1961).

**Trapping and Recombination Time in CdSe.** G. CHEROFF AND S. TRIEBWASSER, *IBM Thomas J. Watson Research Center.*—Measurements of response to sinusoidal variation of incident radiation[1] provide a means complementary to noise studies to measure recombination time, trap capture, and thermal release times in photoconductive processes. This technique has the added advantage of the possibility of relative phase measurements as well as amplitude in order to test models and kinetic hypothesis. In addition, difficulties associated with spurious sources of noise are largely eliminated. Analysis has shown that, from observation of phase and amplitude, it is possible to find recombination time and response time directly and independently. It also is possible to locate trapping levels and measure trap concentrations. The technique has been applied to sintered layers and single crystals of Cu-doped CdSe. Preliminary results show a trapping level at 0.21 ev below the conduction band with a density of $3\times10^{15}$ cm$^{-3}$. It also is possible to use the recombination time measured by this technique to calculate the density of carriers. This can be compared with the density inferred from measurement of conductivity at the same light level. The agreement seen gives confidence that true recombination lifetime is observed.

[1] K. M. Van Vliet, J. Blok, C. Ris, and J. Steketee, Physica **XXII**, 723 (1956); E. A. Niekisch, Z. Physik **161**, 38 (1961).

**Recombination of Electrons and Donors in Semiconductors.** G. ASCARELLI, *University of Illinois,* AND S. RODRIGUEZ, *Purdue University.*—A description is given of a calculation of the recombination of electrons in the conduction band of a semiconductor with ionized donor impurities. The process which we assume consists in the initial capture of the electron in an excited state of the donor center followed by a transition to the ground state. This mechanism is most effective in the case in which all transitions are accompanied with emission or absorption of phonons. The results obtained are compared with earlier theoretical calculations and with experiments. The agreement between the present theory and experiment is reasonably good.

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## Pertaining to The American Physical Society Prize Sponsored by Hughes Aircraft Company

By order of the Council, members of the Society are invited to propose candidates for the 1961 American Physical Society Prize sponsored by Hughes Aircraft Company, and this they may do by writing to Professor M. L. Goldberger, Princeton University, Princeton, New Jersey, who is Chairman of the Committee appointed to nominate candidates. Eventual decision is made by the Council.

This prize is awarded "for an outstanding contribution or contributions to the science of physics, which shall have been published, in a single paper or in more than one paper, in a journal or journals of The American Physical Society or in a journal or journals of the American Institute of Physics. The contribution or contributions must have been made before the prizewinner reached his thirty-third birthday." The prize may not be divided between two or more recipients.

## Optical Society of America Subscription Offer to Members of APS

Individual subscribers to English translations of Russian scientific journals are few, probably because of the high cost of such publications. The Optical Society of America is conducting an experiment with the Russian journal *Optics and Spectroscopy* to discover whether individuals, if given the opportunity to obtain technical translations cheaply enough, will subscribe. This experiment needs the cooperation of scientific societies other than OSA for wider distribution, and so members of The American Physical Society are invited to purchase this worthwhile Russian journal at a relatively low cost of $11 per year. Orders for *Optics and Spectroscopy* should be sent directly to the Optical Society of America, 1155 Sixteenth Street, N.W., Washington 6, D. C.

## Second Announcement of the 1961 Winter Meeting in the West

The 1961 winter meeting of The American Physical Society in the West is to be held at the University of California at Los Angeles on Wednesday, Thursday, and Friday December 27, 28, and 29. A number of invited sessions are planned on theoretical physics, high-energy nuclear physics, accelerator design, electron physics, plasma physics, geophysics, and low-temperature physics (superconducting magnet physics). The geophysics session will be jointly sponsored by the American Geophysical Union, which will concurrently hold meetings on the UCLA campus.

The registration and information desks will be located in the courtyard of the Chemistry-Geology building. Parking facilities beside the Chemistry-Geology building will be available for a small daily fee for members driving to the campus.

Hotel accommodations within walking distance to the campus are the Claremont Hotel (from $5 single, $8 twin beds), and the Dracker Hotel (from $4 single, $8 twin beds). The following motor hotels, located on Wilshire Boulevard, Los Angeles 24, are close to the Village and the campus: Hotel Westwood Plaza (from $6 single, $8 twin beds), Westwood Colonial House (from $6 single, $8 twin beds), Westwood Inn (from $9 single, $12 twin beds), Cavalier Hotel (Singles $10–12), Del Capri (from $13 twin beds). Bel Air Hotel on Stone Canyon Road (from $18.50 singles). Bel Air Sands on Sunset Boulevard (from $13 single, $16 double). Miramar Hotel in Santa Monica (from $11 single, $13 twin). Hilton Hotel in Beverly Hills (from $14 single, $19 twin beds). Surf Rider Inn, Ocean Avenue, Santa Monica (from $9 single, $10 double).

The UCLA Residence Halls offer comfortable accommodations at reasonable rates. The cost, including maid service and breakfast is $4 per person for two in a room and $5 for single occupancy. Common restrooms and baths are conveniently located. Provisions have been made for married couples but the facilities do not allow for housing children under fourteen. If you wish accommodations in a Residence Hall, you must return the coupon on page 489 with a deposit of $5 (checks to be made out to: Regents, University of California) by December 12 to: Conference Coordinator, Sproul Hall, 582 Gayley Avenue, Los Angeles 24, California.

Professor J. R. Richardson of the Physics Department is Chairman of the local committee, and questions concerning physical arrangements should be addressed directly to him. The deadline date for contributed papers was October 20.

## Preliminary Announcement of the 1962 Annual Meeting

The 1962 Annual Meeting of The American Physical Society will be held in New York City on Wednesday, Thursday, Friday, and Saturday, January 24, 25, 26, and 27, 1962. As usual, the American Association of Physics Teachers will hold concurrent sessions and there will be a joint ceremonial session of the two societies, comprising the APS retiring presidential address and the AAPT Richtmeyer Lecture and Oersted Prize presentation. There also will be a business meeting of the Society. The official hotel for the meeting will be the Statler-Hilton, and most of the sessions will be held in the headquarters hotel. It is advisable to make your reservations for this meeting as early as possible. In order to facilitate making your reservations early, a hotel reservation blank has been printed on page 491 of this bulletin. You would be advised to fill this blank out and send it, as soon as possible, to: The Front Office Manager of the Statler-Hilton Hotel, 7th Avenue and 32nd and 33rd Streets, New York 1, New York.

In addition to the scientific sessions held in the Statler-Hilton Hotel, some sessions will be held in the Hotel New Yorker. Deadline day for the meeting is November 10, 1961. Abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

## Preliminary Announcement of the 1962 Southwestern Meeting in Austin, Texas

The 1962 Southwestern Meeting will be held at the University of Texas in Austin, Texas, on Friday and Saturday, February 23 and 24, 1962. Information about hotel accommodations will be published in a future bulletin. Deadline date for the meeting is December 15. Abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

## 1961 Autumn Meeting of the Division of Plasma Physics

Our Division of Plasma Physics will hold its 1961 Autumn Meeting at Colorado Springs, Colorado, from Wednesday through Saturday, November 15 through November 18. Further information may be obtained by writing Dr. Fred L. Ribe, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

## 1961 Annual Meeting of the Division of Fluid Dynamics

Our Division of Fluid Dynamics will convene at Berkeley, California, in the Hotel Claremont near the campus of the University of California, on the three days preceding Thanksgiving: November 20, 21, and 22. This meeting will be devoted to various aspects of the physics of fluids, including hydrodynamics and surface waves, magneto-fluid dynamics, rarefied dynamics, shock-tube and shock-tunnel flows, turbulence and boundary layer phenomena, superfluidity, medical hydrodynamics, and astral fluid dynamics. The object of the Division of Fluid Dynamics is the advancement and diffusion of knowledge of the physics of fluids with special emphasis on the dynamical aspects of liquid, plastic, and gaseous states under all conditions of density and temperature. Further information may be obtained by writing to Dr. Wayland C. Griffith, Lockheed Missiles and Space Division, Palo Alto, California.

**Coupon to be Used for Reservation at Residence Hall for the 1961 December Meeting at UCLA**

UCLA Resident Hall Accommodations

Name (please print) .....

Address: Street City (Zone) State .....

Arrival date Departure date .....

Single: $5 Two in room: $8 .....

Confirmation and additional information will be sent to you by the UCLA conference coordinator.

☐ $5 deposit enclosed

## Hotel Information

## Annual Meeting, New York, N. Y.—January 24–27, 1962

The Statler Hilton is the headquarters hotel. Reservations should be sent directly to Mr. George Mahar, Front Office Manager of the Statler Hilton, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "rollaway" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested, the hotel will hold reservations only to 6 p.m. of the day of your arrival. Checkout time is 3 p.m.

## Hotel Rates

| Hotel | Room and Bath for one per day | Double-Bed Room with Bath for two per day | Twin-Bed Room with Bath for two per day | Suites Living Room Bedroom and Bath for one or two per day |
|---|---|---|---|---|
| Statler Hilton 7th Avenue at 32nd Street | $8–$14.00 | $11.00–$18.00 | $15.00–$22.00 | $36.00–$37.00 |

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off Tear Off

To: Front Office Manager
The Statler Hilton
7th Avenue and 32nd Street
New York 1, New York

**A. P. S.**

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1962 APS. Meeting. I / We plan to arrive ..... and remain until .....

Print below persons in your party.

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

## MEETINGS AND DEADLINES THROUGH APRIL 1962

| Place | Meeting dates | Deadline date |
|---|---|---|
| Los Angeles* | December 27–29 | Past |
| New York | January 24–27, 1962 | November 10 |
| Austin | February 23–24 | December 15 |
| Baltimore | March 26–29 | January 12 |
| Washington | April 23–26 | February 9 |
| Evanston | June 19–21 | April 13 |
| Seattle* | August 27–31 | June 22 |

Abstracts for the meeting marked with an asterisk are to be sent to Professor H. A. Shugart, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date. Abstracts for the other meetings listed above are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 p.m. For meetings handled at this office, *allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west.* Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected. No abstract postmarked (at the point of dispatch) on deadline day ever reaches the office on time, nor does any abstract postmarked at any point west of the Rockies on the day before deadline day. Some abstracts arrive with covering letters dated three or more days before the postmark; it may be a good idea for you to put your abstract into a United States mail box with your own hands. Finally, if time is scant, fold your abstract and mail it in an envelope of size 9½ by 4¼ inches or thereabouts; for if you mail it in a "manila" envelope large enough to accommodate it without folding, it may very well arrive after the deadline. *The privilege of contributing papers to meetings of The American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

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## DIVISIONAL MEETINGS AND TOPICAL CONFERENCES (see page 488)

| | | | |
|---|---|---|---|
| Colorado Springs | Plasma Physics | November 15–18 | Past |
| Berkeley | Fluid Dynamics | November 20–22 | Past |

## RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words or to its actual length in words, whichever is the greater; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words. By-lines are not counted as part of the 200 words, and therefore addresses are condensed to the minimum in them. If you want to spend a lot of your precious 200 words in describing your exact location and the exact compartment of your organization in which you work, you have that privilege.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original*, the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts* (including titles, by-lines, and footnotes) *must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. *Tables too broad to fit into one column of the Bulletin will be left out.* The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go into the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after it has been received. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

### *New Instructions*

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *In general, all instructions about an abstract should be typed at the bottom of the page that has the abstract on it, never in a covering letter. Covering letters get separated from abstracts!*

(*c*) *If a member insists that his paper be scheduled for a particular day or not on a particular day, he will get his wish, but usually at the price of having his contribution included in a session to which it is irrelevant.*

# The American Physical Society

OFFICERS OF THE SOCIETY FOR 1961

| | | |
|---|---|---|
| *President* | FREDERICK SEITZ | University of Illinois |
| *Vice-President* | W. V. HOUSTON | William Marsh Rice University |
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| *Treasurer* | S. L. QUIMBY | Columbia University |
| *Managing Editor* | S. A. GOUDSMIT | Brookhaven National Laboratory |

*Past Presidents now on Council:* W. F. G. Swann, J. W. Beams, G. E. Uhlenbeck, and V. F. Weisskopf.

*Other members of the Council:* W. A. Fowler, Charles Kittel, Harvey Brooks, Charles Hard Townes, N. E. Bradbury, D. W. Kerst, L. G. Elliott, and P. Kusch; also W. P. Slichter elected by Council.

| | | |
|---|---|---|
| *Deputy Secretary* | W. W. HAVENS, JR. | Columbia University |
| *Deputy Secretary for the Pacific Coast* | HOWARD SHUGART | University of California, Berkeley |

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*Please cut along this line*

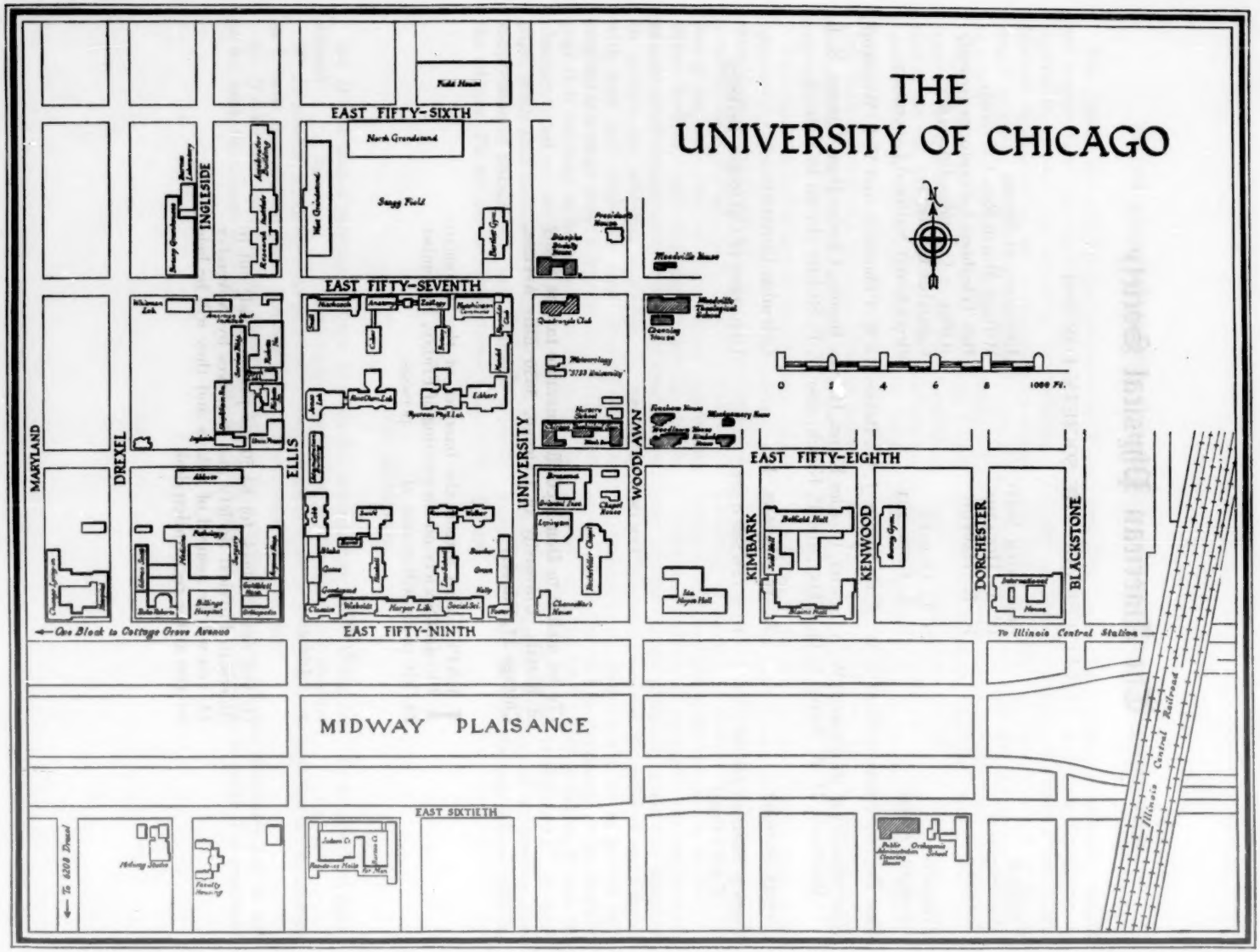
**(To be mailed to Don McGiffin, Institute for the Study of Metals, University of Chicago, 5630 Ellis Avenue, Chicago 37, Illinois)**

I EXPECT to attend the banquet of the American Physical Society on the evening of Friday, November 24. My party will consist of ..... persons.

(*Name*).....

(*Address*).....

(If you send a check for $4.50 per person, made out to American Physical Society and it arrives by November 22, you will be assured of tickets and they will be held for you at the registration desk.)


THE
UNIVERSITY OF CHICAGO
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MARYLAND
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KENWOOD
DORCHESTER
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Stagg Field
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Ida Noyes Hall
Bartlett Hall
Illinois Central Railroad
To Illinois Central Station
One Block to Cottage Grove Avenue
To 60th Street
0 2 4 6 8 1000 Ft.